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THE MECHANISM OF THE GENESIS OF POLYMORPHOUS FORMS

MORTIMER C. BLOOM, *Mineralogical Laboratory,
Massachusetts Institute of Technology.*

INTRODUCTION

Despite the steady growth of our knowledge of polymorphic phenomena,¹ we have at present almost no knowledge of the factors which determine what particular crystalline form will be generated when a solid is deposited from a vapor, from a melt, or from a solution. We have learned that only one modification of a given chemical species can be thermodynamically stable over certain ranges of temperature and pressure, and that within this region all other modifications tend to transform to this modification. We find in nature, however, many polymorphous forms far from their regions of thermodynamic stability. If this were due to the fact that high temperature forms, generated at temperatures within their region of stability have subsequently cooled without transformation, the presence of such high temperature forms would be an excellent basis for geological thermometry. Unfortunately, the hypothesis that high temperature forms, generated at temperatures within their thermodynamic stability region, have subsequently cooled without transformation, is not adequate to explain the known phenomena. To mention a few examples, cristobalite, with a stability range above 1470°C., has been formed by heating silica gel² with a melt of NaPO₃ at temperatures under 750°C. Wurtzite, with a stability range above 1020°C., has been obtained at 250° from an acid solution.^{3,4} Metacinnabarite and marcasite, for which no stability regions have yet been

¹ BUERGER, M. J. and BLOOM, M. C., Crystal polymorphism: *Zeits. Krist. (A)* **96**, 182-200 (1937).

² PEYRONEL, GIORGIO, Cristallizzazione della Silice in NaPO₃: *Zeits. Krist.*, **95**, 274 (1936).

³ ALLEN, E. T., CRENSHAW, J. L. and MERWIN, H. E., The sulphides of zinc, cadmium, and mercury; their crystalline forms and genetic conditions: *Am. Jour. Sci.*, Series 4, **34**, 341 (1912).

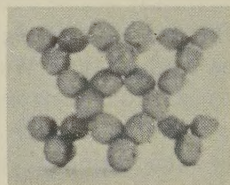
⁴ ALLEN, E. T., CRENSHAW, J. L. and MERWIN, H. E., Effect of temperature and acidity in the formation of marcasite (FeS₂) and wurtzite (ZnS): *Am. Jour. Sci.*, Series 4, **38**, 393-431 (1914).

found, have similarly been generated from acid solutions at moderate temperatures^{3,4} and aragonite, whose stability region is below 0°C. at atmospheric pressure⁵ is readily generated under normal pressure conditions at room temperature by the addition of small quantities of extraneous material, such as strontium or lead salts to solutions which in their absence precipitate the stable calcite.⁶

A few workers have suggested possible causes for this anomalous behavior. Johnston, Merwin, and Williamson,⁷ in 1916, offered the hypothesis with regard to aragonite, that since its solubility is close to that of calcite, a small amount of solid solution in the aragonite structure might make it less soluble than calcite in contact with certain solutions, and thus make it a truly stable phase as precipitated from such solution. They made no attempt, however, to give reasons why such solid solution should take place in the aragonite structure in preference to the calcite structure.



Low
Quartz



High
Cristobalite

FIG. 1

More recently, Buerger,⁸ on the basis of crystal structure evidence, has offered an explanation of why the high temperature forms of certain minerals should have a preferential capacity for forming solid solutions with extraneous materials. He pointed out that of the three major stable crystalline forms of silica, quartz is a relatively closely packed structure, while the stable high temperature forms, tridymite and cristobalite, are very open ones (Fig. 1). Hence the high temperature forms might be expected to show a marked preferential tendency for interstitial solid solution. He reasoned that the high cristobalite solid solutions produced in this manner would have stability ranges different from those of the

³ BACKSTROM, H. L. J., Über die Affinität der Aragonit-Calcit Umwandlung: *Zeits. phys. Chem.*, **97**, 179 (1921).

⁴ CREDNER, H., *J. prakt. Chem.*, **2**, 292 (1870).

⁷ JOHNSTON, J., MERWIN, H. E., and WILLIAMSON, E. D., The several forms of calcium carbonate: *Am. Jour. Sci.*, Series 4, **41**, 473-512 (1916).

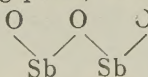
⁸ BUERGER, M. J., The silica framework crystals and their stability fields: *Zeits. Krist.*, **90**, 186-192 (1935).

pure substance, and that high cristobalite found at room temperature in opals and elsewhere may be, or may have been, such a stable solid solution.

One other hypothesis, which has been made in this connection, is that of Cohen and Moesveld.⁹ These authors postulated that when the solution of a substance reaches the saturation point, adsorption of impurities on the nuclei of the stable form may inhibit the precipitation of this form and induce supersaturation. If the supersaturation concentration of an unstable form is thus exceeded, the unstable form may appear. If the unstable form has much less adsorptive tendency for the impurities than the stable form, the unstable form may appear exclusively; or a mixture of the two forms may be obtained. An apparently identical mechanism was subsequently postulated by C. H. Saylor¹⁰ as a result of additional studies of the calcite-aragonite relation. This picture of the mechanism of the genesis of unstable forms requires a knowledge of adsorption phenomena on nuclei for its verification. Such knowledge is not available.

THE Sb_2O_3 SYSTEM

In order to test the hypothesis of solid solution in open structures as a cause of the genesis of unstable forms, a study of the Sb_2O_3 system was undertaken. This system has properties which make it particularly suitable and convenient for this purpose. The low temperature form senarmontite, stable up to 570°C .,¹¹ is an isometric arrangement of discrete Sb_4O_6 molecular clusters¹² (Fig. 2). Such clusters are apparently very stable units, for gas density measurements indicate their presence even in the vapor phase. The high temperature form, valentinite, stable between this temperature and the melting point,¹¹ is an orthorhombic structure¹³ (Fig. 3) made up of chains of O O O linkages which



fit into each other (as shown on the bc projection) to form nearly planar rectangular sheets one linkage wide. Each sheet extends indefinitely in the c axis direction and is connected through O—O contacts to a neighboring sheet, leaving an interstitial hole parallel to the c

⁹ COHEN, ERNST and MOESVELD, A. L. TH., Die Metastabilität der Elemente und Verbindungen als Folge von Enantiotropie oder Monotropie, I: *Zeits. phys. Chem.*, **94**, 450–481 (1920).

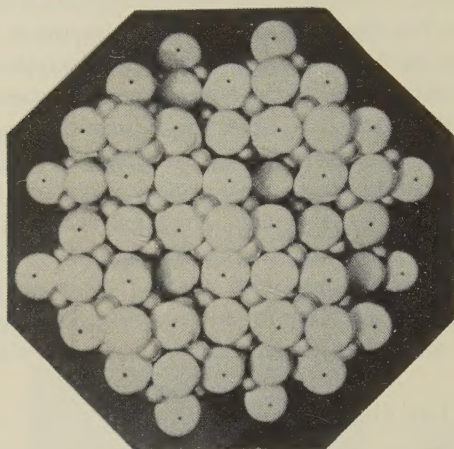
¹⁰ SAYLOR, C. H., Calcite and aragonite: *Jour. phys. Chem.*, **32**, 1460 (1928).

¹¹ ROBERTS, E. J. and FENWICK, F., The antimony electrode: *Jour. Am. Chem. Soc.*, **50**, 2134 (1928).

¹² BOZORTH, R. M., The crystal structures of the cubic forms of arsenious and antimonous oxides: *Jour. Am. Chem. Soc.*, **45**, 1621 (1923).

¹³ BUERGER, M. J. and HENDRICKS, S. B., The crystal structure of valentinite (Orthorhombic Sb_2O_3): *Zeits. Krist. (A)*, **98**, 1–30 (1937).

axis between each four sheets (as shown in the *ab* projection). The difference in crystal systems makes microscopic identification a comparatively simple matter of looking for birefringence, and the very very marked difference in structure simplifies the structural reasoning.



Senarmontite

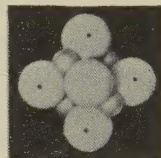
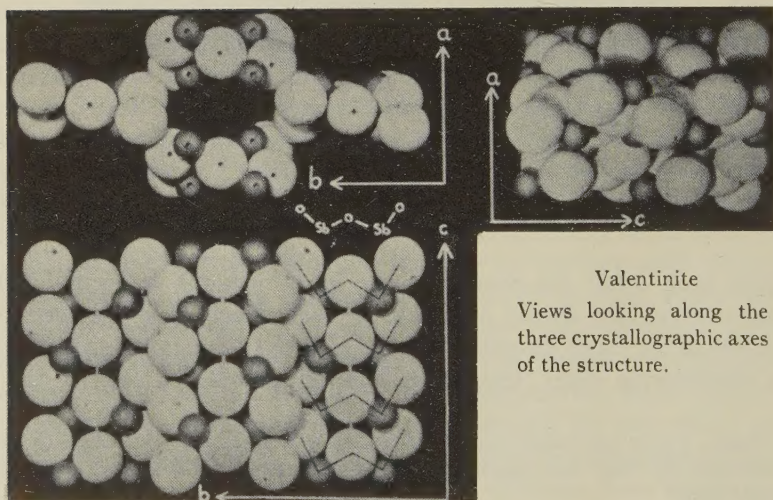
 Sb_4O_6 Molecule

FIG. 2



Valentinite

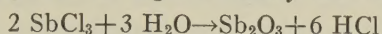
Views looking along the three crystallographic axes of the structure.

FIG. 3

Moreover, the anomalous genesis of a high temperature form is shown to a marked degree by this system in nature; and the anomaly is readily reproduced in the laboratory. Thus the high temperature form (valentinite) is found widely distributed in nature as a surface alteration product

of stibnite, despite the fact that its normal stability range is in excess of 570°C.

In the laboratory, valentinite is readily obtained by hydrolysis of antimony chloride with distilled water at room temperature.¹⁴ During the course of this hydrolysis, HCl is generated by the reaction:



and the products retain HCl so firmly at room temperature that three months' washing with distilled water under constant agitation does not suffice to remove this HCl completely. It may be removed by treatment with alkali, but in this case, the removal is accompanied by transformation to the stable senarmontite. These facts are all in accord with the hypothesis of solid solution in the high temperature form as the cause of the genesis of this form.

THERMODYNAMIC STABILITY CONSIDERATIONS

It now becomes of interest to ask whether these HCl-bearing solid solutions in the valentinite structure are truly stable phases in contact with the solutions from which they were generated. To make a rigorous test of the thermodynamic stability of this HCl-bearing valentinite, solubility measurements were made as follows:

Antimony trichloride, prepared as previously described,¹⁴ was melted and poured in varying quantities into bottles each of which contained five liters of water (distilled from alkaline permanganate). The flocculent precipitates initially obtained were allowed to equilibrate in contact with their respective solutions for six months at laboratory temperatures. At the end of this period, one liter of supernatant liquor was removed from each sample and to it was added finely powdered pure senarmontite. This senarmontite had been prepared by triple sublimation, at 500°C. in vacuo, of an antimony chloride hydrolysis product which had been washed with distilled water under constant agitation for three months and which contained, prior to the sublimation, less than 0.05% chloride as an impurity. The solutions were allowed to remain side by side in contact with their respective solid phases for two more months at laboratory temperatures. At the end of this period, analysis yielded the following results:

<i>Run No. 1</i>	<i>Chloride* in Solution</i>	<i>Antimony** in Solution</i>
Valentinite	.0083 normal	.000093 normal
Senarmontite	—	.000039
<i>Run No. 2</i>		
Valentinite	.0055 normal	.000090 normal
Senarmontite	—	.000036

¹⁴ BLOOM, M. C. and BUEGER, M. J., On the genesis of polymorphous forms— Sb_2O_3 : *Zeits. Krist. (A)*, **96**, 365–375 (1937).

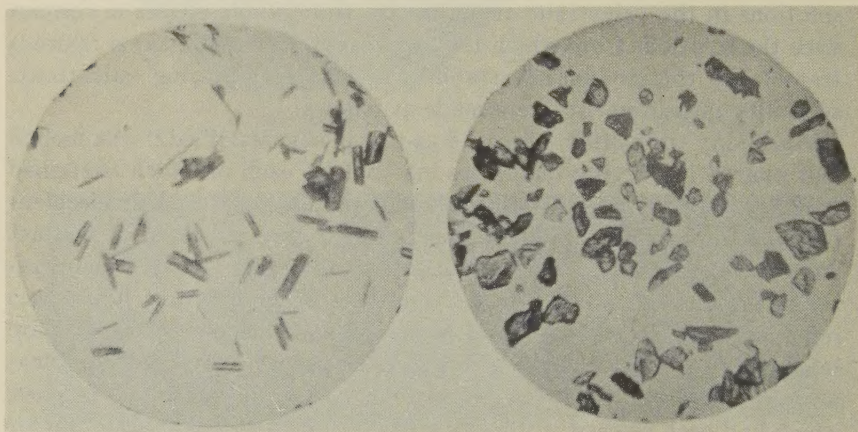
Re-analysis, after standing an additional twelve months in contact with the respective solid phases as before, yielded:

<i>Run No. 1</i>	<i>Chloride in Solution</i>	<i>Antimony in Solution</i>
Valentinite	.0084 normal	
Senarmontite	.0084	
<i>Run No. 2</i>		
Valentinite	.0056	.000092 normal
Senarmontite	.0056	.000040

* Accuracy \pm .0002

** Accuracy \pm .000003

The conclusion seems unavoidable that the valentinite is the more soluble and hence the unstable phase unless it is showing excess solubility due to small crystal size. To test this possibility, microscopic examination was made and it was found that the valentinite crystals were of the same order of magnitude as the senarmontite crystals (Fig. 4).



Valentinite $\times 65$

Senarmontite $\times 65$

FIG. 4

The evidence seems conclusive that the valentinite is not a thermodynamically stable phase, except in the sense that it is apparently in equilibrium with the solution from which it was grown. Evidently the passive resistance to reorganization of the structure allows equilibrium to exist at a higher free energy than the minimum for the system.

THE MECHANISM OF PRECIPITATION

Since true thermodynamic stabilization by solid solution in the high temperature structure does not account for the observed phenomenon, we must look to extra-thermodynamic causes for the explanation of this

anomalous genesis of the high temperature form. The fact that we must look to extra-thermodynamic causes for the explanation of crystallization phenomena has been demonstrated by a series of researches by DeCoppet,¹⁵ Tammann¹⁶ and Othmer¹⁷ which, apparently, have not received the attention which they deserve in this connection. The idea of metastable and labile regions, and the so-called "Law of Stages" which have long been associated with the name of Wilhelm Ostwald, and which are still used in the explanation of the genesis of crystal forms, have been shown by the above mentioned researches to be not very useful, and, in some cases, hardly tenable concepts. These investigators present evidence that the region of metastability, postulated by Ostwald, is a function of the time one is willing to wait for the observance of the formation of crystals, as well as of the size of the sample used. They show that the use of very long times and very large samples enables spontaneous crystallization to be observed at temperatures close to the melting point. They have demonstrated that there is no general rule governing what particular form will appear when solid phases are generated; that in some cases only the unstable form is obtained, in other cases only the stable form is obtained, but that in many cases both forms appear simultaneously. They have shown further, that the presence of small quantities of impurities often have a marked effect upon the number and the nature of the nuclei formed; some impurities favor the formation of the stable form, and others favor the formation of unstable forms. The data of these investigations leave little room for doubt that the development of crystalline nuclei from vapor, from melt, or from solution is a chance phenomenon.

If the development of crystal nuclei is a chance phenomenon, it follows that the type of structure generated from solution should depend, first, upon the nature of the groups present in the solution prior to the deposition of the solid phase and, second, upon the nature of the available crystal structures into which these groups may aggregate. The presence of dissolved impurities may affect the probability of precipitation in a given structure in a number of ways. Several ways in which they may be thus effective are:

- (1) They may induce changes in the numerical relationships between

¹⁵ DECOPPET, L. G., Recherches sur la surfusion et la sursaturation: *Ann. chim. phys.*, (8) **10**, 457-527 (1907).

¹⁶ TAMMANN, G., The transition of an unstable into a stable stage of aggregation: Chapter IX of "States of Aggregation," translated by R. F. Mehl, D. Van Nostrand, New York (1925).

¹⁷ OTHMER, P., Studien über das spontane Kristallisations-vermögen: *Zeits. anorg. Chem.*, **91**, 209-247 (1915).

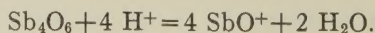
groups already present in the solution (change of pH , of ionization, etc.).

(2) They may cause the formation of new groups (complex ion formation, etc.).

(3) They may act as local disturbances causing local changes of orientation and energy distribution.

(4) They may act as inert obstructions reducing the number of collisions of molecules of the precipitating substance. In any of these cases, the probability of crystallization would in general be diminished and the probability of supersaturation correspondingly enhanced. This is in accord with the known effect of solute impurities on supersaturation.^{15,18} If, however, there is a solid structure which can readily house the given impurity in solid solution, the effect of this impurity in inhibiting aggregation into such a structure should be small. Consequently, it is to be expected that the probability of precipitation of a structure of this type will be greater, in the presence of the impurity, than that of structures which cannot readily accommodate the foreign material. The precipitated solid may be thermodynamically stable or unstable with respect to forms of the ideally pure compound, since the postulated factors affecting the probability of precipitation have no necessary relation to thermodynamic stability. However, solid solution in a structure as here postulated will decrease the solubility of the structure and, if a sufficient amount of the impurity can be accommodated in the solid solution, it may effect true thermodynamic stabilization of a structure which in the absence of such solid solution is not the stable one.

We shall now apply these considerations to the precipitation of Sb_2O_3 . It has previously been mentioned that Sb_4O_6 clusters are evidently very stable units. It is these that are found as the molecular unit in the gas phase and it is these that we would expect to find as the un-ionized aggregates in solution. In the case under consideration, the hydrolysis of $SbCl_3$, HCl is generated giving as impurities in the solution hydrogen ion (H^+) and chloride ion (Cl^-). The effect of H^+ upon aqueous antimonous solutions is revealed by the data of Schuhmann.¹⁹ The effect is the production of SbO^+ according to the equation:

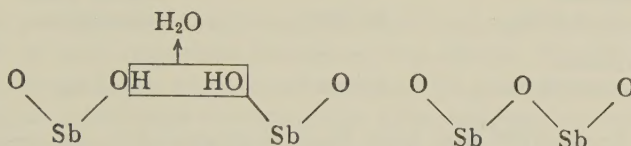


The effect of Cl^- is presumably that of cases (3) or (4) above. Let us ask, therefore, "what is the relationship between the presence of SbO^+ and Cl^- , and the development of the high temperature structure?"

¹⁸ COHEN, ERNST and MOESVELD, A. L. TH., Kristallisations-vermögerung in übersättigten Lösungen: *Zeits. phys. chem.*, **94**, 482-504 (1920).

¹⁹ SCHUHMANN, REINHARDT, The free energy of antimony trioxide and the reduction potential of antimony: *Jour. Am. Chem. Soc.*, **46**, 57 (1924).

The mechanism of formation of oxides from aqueous solution is, in general, the initial formation of groups containing hydroxyl ion (OH^-) and subsequent dehydration. This must be the case unless we assume an appreciable concentration of oxide ion (O^{--}). In the cases of iron, aluminum and manganese, the intermediate hydroxyl-bearing products are known in the solid state and recent crystal structure evidence has shown that they are respectively FeOOH ,²⁰ AlOOH ²¹ and MnOOH ²² linkages. If we postulate the formation of such a linkage in the case of antimony, we should obtain SbOOH which, by elimination of H_2O between two such groups, would give rise to a chain of the following character:



It has previously been pointed out that such a chain is the fundamental unit of the valentinite structure. It has also been pointed out that the low temperature senarmontite structure is composed of discrete Sb_4O_6 molecules and it might be expected, therefore, that acid solutions which break up these molecules into SbO^+ would tend to produce the high temperature structure. Turning now to the effect of Cl^- , detailed examination of the valentinite structure reveals that the "holes" in the structure are capable of housing a spherical atom of approximately 1.6 \AA in radius. This is apparently adequate for the housing of HCl , which in the gas phase has an equilibrium distance of 1.272 \AA between atomic centers.²³ Looked at from another point of view, the chloride ion radius²⁴ is 1.81 \AA in six co-ordinated ionic crystals, and contraction due to decrease of co-ordination might well allow interstitial accommodation in the above structure. We should not expect the presence of Cl^- , therefore, to inhibit the development of the valentinite structure.

Additional experimental results are summarized in the following table:

²⁰ GOLDSZTAUB, S., Structure de la goethite: *Bull. Soc. Franc. Min.*, **58**, 25-43 (1935).

²¹ TAKANÉ, K., Crystal structure of diasporite: *Proc. Imp. Acad. Japan*, **9**, 113-116 (1933).

²² BUERGER, M. J., The symmetry and crystal structure of manganite, $\text{Mn}(\text{OH})\text{O}$: *Zeits. Krist. (A)*, **95**, 163-174 (1936).

²³ JEVONS, W., Report on band spectra of diatomic molecules: *Physical Society, London*, page 276 (1932).

²⁴ STILLWELL, C. W., Crystal Chemistry, Chapter II. The Sizes of Atoms and Ions. McGraw-Hill Book Company, 1938.

THE INFLUENCE OF SOLUTION COMPOSITION UPON THE STRUCTURE
OF THE PRECIPITATED PHASES OF Sb_2O_3

<i>Method</i>	<i>Temperature</i>	<i>Precipitated Phase</i>
Air oxidation of antimony under distilled water	25°	Senarmontite
Precipitation from .01 N HCl	25°–100°	Valentinite
Precipitation from .01 N H_2SO_4	25°–100°	Valentinite
Precipitation from .01 N HClO_4	25°–100°	Mixture mostly senarmontite
Precipitation from .06 N HClO_4	25°–100°	Valentinite

It will be observed that when Sb_2O_3 is generated by air oxidation of antimony under distilled water, that is, in the absence of dissolved impurities, that the stable senarmontite structure is obtained. H_2SO_4 acts just as HCl does, and we see here the mechanism of the genesis of valentinite by weathering of stibnite. The oxidation of the sulphide produces sulphate, which with water produces H_2SO_4 and thus causes the generation of valentinite. It will be noted, however, that in the case of HClO_4 it is necessary to raise the acid concentration to much higher values than in the case of HCl or H_2SO_4 in order to obtain the exclusive generation of the valentinite structure. For an explanation of this, we must look to the difference in the influence of the Cl^- , SO_4^{--} , and ClO_4^- . The sulphate radical is known from crystal structure evidence to consist of a tetrahedral arrangement of oxygens about the sulphur, the O—O distance along the tetrahedral edge being 2.44 \AA .²⁵ The direct interstitial accommodation of such a tetrahedron would not be possible without some distortion of the structure, but if one of the oxygens of the SO_4^{--} radical replaces the normal oxygen of the valentinite structure, the tetrahedron could easily be accommodated within the available space without any distortion, and the requirements of valence and electrical neutrality would be satisfied. Since such a replacement would alter neither the Sb—O relations of the valentinite structure nor the type of Sb— SO_4^{--} bonds which may be presumed to exist in $\text{Sb}_2(\text{SO}_4)_3$, this mechanism of solid solution appears quite probable.

The perchlorate radical is known from crystal structure evidence to consist of an entirely analogous tetrahedral arrangement of oxygens

²⁵ *Zeits. Krist., Strukturbericht*, Bd. II, page 84 (1937).

about the chlorine, the O—O distance (along the tetrahedral edge) in this case being 2.65 Å.²⁶ The distortion of the structure necessary to accommodate such an ion by direct interstitial solid solution is of course still greater and no analogous substitution mechanism satisfying valence and neutrality requirements is available. The presence of ClO_4^- would therefore be expected to hinder development of the valentinite structure. This is the probable explanation of the fact that higher hydrogen ion concentrations are required for the exclusive generation of the valentinite structure in the presence of HClO_4 than in the presence of HCl or H_2SO_4 .

DISCUSSION AND CONCLUSIONS

In the precipitation of antimony trioxide from aqueous solutions, the presence of acid impurities introduces two effects. The H^+ causes a marked change in the number and nature of the groups present, and the anion of the acid acts as an obstruction to the aggregation of the groups into a solid structure. A study of the crystal structures of the two forms in relation to the nature of the groups in solution prior to precipitation gives a picture of the probable mechanism of the genesis of the polymorphous forms of this substance. The profound effect of hydrogen ion concentration as well as the subsidiary effect of the anion upon the genesis is satisfactorily accounted for by this mechanism. The reason that the high temperature form (valentinite) is found widely distributed in nature as a surface alteration product of stibnite is indicated.

We may expect to find analogous mechanisms in operation with other oxides, with sulphides, and with carbonates, for in all these cases, H^+ will have a marked effect upon the number and nature of the groups present in solution. In the case of sulphides, the instability of sulphide ion (S^{--}) makes $\text{X}-(\text{SH}^-)^*$ bonding and subsequent elimination of H_2S an almost inevitable mechanism of sulphide formation from acid solutions. For example, the complete precipitation of Hg, Cd, Cu, Bi, As, Sb, Sn as sulphides is commonly effected in analytical chemistry from solutions approximately 0.3 normal in acid. Using the solubility and equilibrium constant data of the International Critical Tables, one may calculate that such a solution contains not more than one sulphide ion (S^{--}) in 100 cc. of solution. There are approximately 2×10^{15} hydrosulphide ions (SH^-) in the same volume.

It would appear that the anomalies connected with the genesis of unstable polymorphous forms are due to the fact that the development of crystal nuclei is a chance phenomenon and depends, therefore, upon

²⁶ *Zeits. Krist., Strukturbericht*, Bd. II, page 88 (1937).

* X = any positive ion, (SH^-) = hydrosulphide ion.

two major factors: (1) the groups present in the vapor, melt, or solution prior to the development of the solid phase, (2) the possible crystal structures into which these groups may aggregate. As a result, the solid phase which precipitates may be thermodynamically stable or unstable since the factors, above outlined, which determine the structure of the precipitated phase have no necessary relation to thermodynamic stability. In the case of precipitation from solution, the presence of dissolved impurities may change the nature of the structure which is precipitated due to two major effects: (1) They may change the number or the nature of groups present, (2) they may act as obstructions to the aggregation of the groups into a solid structure. The second of these effects might be expected to favor the precipitation of open structures capable of housing the dissolved impurities in solid solution. Such solid solution in a structure will reduce the solubility and may thus, if a sufficient amount of the impurity can be accommodated, effect true thermodynamic stabilization of an otherwise unstable structure. This is not, however, a necessary condition for its appearance.

ANTLERITE

CHARLES PALACHE, *Harvard University, Cambridge, Mass.*

Antlerite was first described by Hillebrand (1889) who gave an incomplete physical description and a chemical analysis, naming the mineral from its place of occurrence, the Antler mine, Arizona. Ten years later it was described under the name stelznerite from Chile. The study by Arzruni and Thaddéeff (1899) was communicated posthumously by Dannenberg. Schaller (1911) proved the identity of the two minerals optically and advocated the use of the prior name, a usage which has been followed except in German publications. The fullest description of the crystallography of antlerite is by Ungemach (1924), who seems to have been the first to recognize the mineral at Chuquicamata, Chile. It had been commonly mistaken there for brochantite, but is now known to be the principal ore (Audrieth, 1925; Bandy, 1938) in this largest of the world's copper mines.

The author became interested in the study of antlerite through a specimen from Bisbee, Arizona, brought to his attention by Dr. Tunell. These crystals were derived from a single and very handsome specimen in the U. S. National Museum, the antlerite being implanted on brochantite. At about the same time a series of complex crystals of antlerite were sent to the Harvard Mineralogical Laboratory by O. W. Jarrell, then of the geological staff at Chuquicamata. The results of the study of these crystals are presented below.

Search of the specimens of brochantite in the Harvard collections to see if any were mislabeled and were really antlerite was largely negative. Only one specimen labeled brochantite was found to be antlerite, the crystals forming a fine felt embedding earlier atacamite. The locality given, La Lama, Chile, could not be found on our maps. The specimen is very similar in appearance to one from the original stelznerite locality, Remolinos, Vallenar, Chile.

Additional localities for antlerite represented in the Harvard collection are Sierra Mojada, Coahuila, Mexico, a mass of finely fibrous material, quite friable, of a light green color; and a specimen of similar appearance collected by Dr. Foshag at Northern Light Mine, Warsuk Range, near Black Mountain, Nevada. Antlerite was found among the oxidation products of chalcocite in the Jumbo Mines, Kennecott, Alaska, by Bateman and McLaughlin (1920). The crystallography of the mineral from Chuquicamata, Chile, and from Bisbee, Arizona, will be described below.

Posnjak and Tunell (1929) have made an exhaustive study of the artificial formation of this and other sulphates of copper.

Ungemach, in describing antlerite, adopted the position previously employed in descriptions of the artificial salt. This position makes the main zone and the elongation of most crystals the direction of the *a*-axis. Following the newer usage of this laboratory, the author places this dominant zone vertical, thus interchanging the *a* of Ungemach with his *c*-axis, which change leaves the perfect cleavage parallel to (010). A second cleavage, much poorer, is parallel to (100). The transformation formula, Ungemach to Palache, is 001/010/100.

This position brings out the close similarity between antlerite and atacamite. Because of their deep green color and perfect (010) cleavage, these two minerals can hardly be distinguished except by crystallographic or optical measurements. Brochantite is also indistinguishable from either by inspection alone. In the accepted orthorhombic interpretation of brochantite, the perfect cleavage is likewise (010); and, as pointed out by Tunell (1929, p. 23), the minerals have similar refractive indices, in the same optical orientation. But the new monoclinic interpretation of brochantite* makes the cleavage (100), and the parallelism between the properties of these three similar minerals is thus modified.

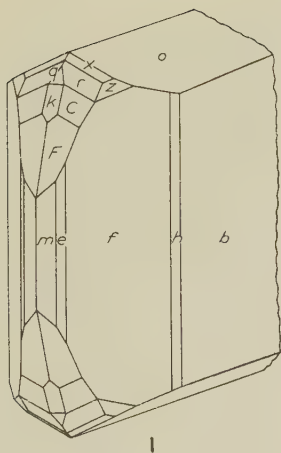
The optical characters of antlerite, as given by Tunell (1929) and in the tables of Larsen but oriented to the new position are:

Optically positive. $2V = 53^\circ$
 $X = b, 1.726$; yellow green
 $Y = a, 1.738$; blue green
 $Z = c, 1.789$; green

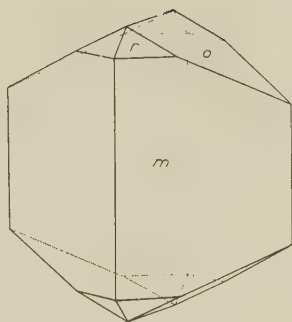
The specific gravity, as determined by Dr. Berman on two samples on the micro-torsion balance, is $3.88 \pm .005$.

Antlerite crystals from Bisbee are illustrated in Fig. 1. The crystals are thick tabular with dimensions of about 3 by 3.5 mm. and 2 mm. thick. They are dark green and appear almost black except on cleavages. Their faces are brilliant and free from striations, except a series of rather deep grooves on the faces of (011) parallel to [100] and not shown in the drawing. The numerous pyramid forms shown are somewhat exaggerated in the figure, especially (311); they are, however, present on all the crystals and generally with their full number of faces. Three crystals were measured and yielded a form list including most of Ungemach's forms and several new ones. Almost all of these new forms reappeared on the Chilean crystals, a welcome confirmation.

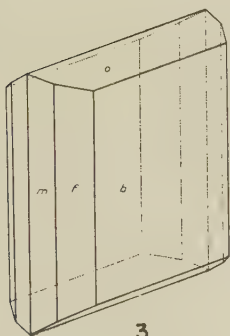
* Unpublished study, soon to appear.



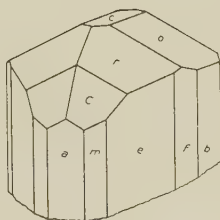
1



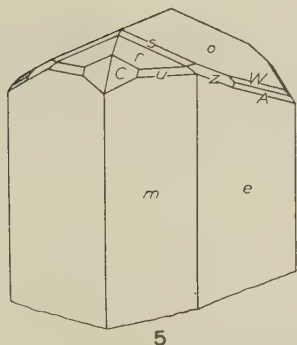
2



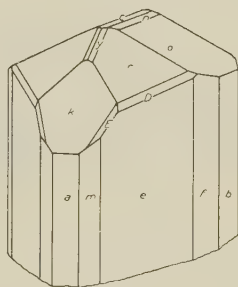
3



4



5



6

FIG. 1. Crystal of antlerite, Bisbee, Arizona.

FIG. 2. Crystal of antlerite, Chuquicamata, Chile. The commonest type of crystal.

FIG. 3. Crystal of antlerite, tabular habit, Chuquicamata.

FIGS. 4, 5, 6. Crystals of antlerite, prismatic habit, Chuquicamata.

The most important locality for antlerite is, however, that of Chuquicamata, where it constitutes the main ore mineral. Its typical mode of occurrence is in cross-fibre veins ranging in thickness from thin films up to as much as 2.5 cm. in section. The crystals are of extremely diverse habit. Most common is such a simple combination as was shown by Ungemach, reproduced except for (010) in Fig. 2. The double termination, as shown here, is very exceptional and was seen only when the mineral was embedded in kroehnkite. Generally, the crystals are implanted by an end of the vertical axis and are slightly elongated on [001]; but they may be thin tabular parallel to (010) as in Fig. 3 or stout, and rather stubby, square prisms as in Figs. 4, 5 and 6.

Table 1 shows the observed combinations of the antlerite forms. The last two columns refer to the two crystals figured by Ungemach (1924). From this table it is evident that the dominant forms on antlerite crystals are $b(010)$, $e(120)$, $m(110)$, $o(011)$, $k(201)$, $r(111)$ and $C(211)$. The forms $h(140)$, $f(403)$, and $B(151)$ were found only on the Bisbee crystals. It will be noted that of the forms found by Ungemach only $g(560)$ and $l(133)$ were not again found on our crystals.

The new forms accepted as established and indicated in the angle table by an asterisk are based on the observations of Table 2. Three Arizona crystals and eight from the Chilean locality were measured. All the measurements were made in the position of Ungemach, since the author only after long deliberation decided to change the orientation. The angles are presented as measured and can be compared with the values of the angle table by taking $\phi = 90 - \phi_1$, $\rho = \rho_1$. It will be noted that several forms are based on a single measurement; but, in all but one of these, position of the face in a zone, together with the angles, seemed enough to assure the form.

Axial ratios were calculated for both lots of crystals, and results were obtained very similar to those of Ungemach. The author's more abundant observations have been averaged with his, and the angle table is calculated on the new elements and in the changed position. This table supersedes that published from this laboratory in 1933.

TABLE 1. ANTLERITE COMBINATIONS

		Arizona			Chuquicamata, Chile									
		1	2	3	4	5	6	7	8	9	10	11	12	13
<i>c</i>	001							x			x			x
<i>b</i>	010	x		x	x	x	x			x	x	x	x	x
<i>a</i>	100			x				x			x	x		
<i>h</i>	140	x	x											
<i>f</i>	130	x	x				x	x		x	x	x		x
<i>e</i>	120	x	x			x	x	x	x	x	x	x		x
<i>i</i>	230						x							x
<i>g</i>	560													x
<i>m</i>	110	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>n</i>	013										x			
<i>o</i>	011	x	x	x	x	x		x	x		x		x	x
<i>q</i>	403	x	x	x										
<i>k</i>	201	x	x	x						x	x	x		x
<i>r</i>	111	x	x	x	x			x	x	x	x	x	x	x
<i>u</i>	221								x					
<i>v</i>	123											x		
<i>t</i>	133													x
<i>s</i>	122	x	x	x					x	x				x
<i>w</i>	142								x					
<i>x</i>	233	x	x	x								x		
<i>y</i>	313										x	x		
<i>z</i>	121	x	x	x			x		x					
<i>A</i>	131		x	x			x		x		x			
<i>B</i>	151		x	x										
<i>C</i>	211	x	x	x			x	x		x				
<i>D</i>	231										x	x		
<i>E</i>	522										x	x		
<i>F</i>	311	x	x	x							x	x		
Fig.		1			2	3		4	5		6		U	U

TABLE 2. ANTILERITE: MEASURED ANGLES OF NEW FORMS

Form	Crystals		Cal. angles		Meas. angles		Range		In zone
	Ariz.	Chile	ϕ	ρ	ϕ	ρ	ϕ	ρ	
100	1	2	90°00'	90°00'	(used for orientation)				[001]
013	—	2	80 29	90 00	81°22'	90°00'	23'	0°	[100] and [031]
403	3	—	90 00	45 41½	90 04	46 00	4	38	[010]
221	—	1	44 50½	44 05	44 50	44 10	—	—	[110]
123	—	1	71 28	76 58½	71 45	76 30	—	—	
142	—	1	44 50½	75 31½	44 50	76 00	—	—	[211]
233	2	1	63 18½	66 26½	63 32	66 34½	2	9	
313	—	2	80 29	54 10	80 32	54 14	23	10	
121	3	2	44 50½	62 41½	44 50	62 48	25	28	[111]
131	2	3	33 32½	67 58½	33 23	68 02	89	78	[211]
151	2	—	21 40½	74 51½	21 33	75 09	36	35	
211	3	3	63 18½	37 23½	63 19	37 19	12	12	
231	—	1	33 22½	51 01½	34 39	51 30	—	—	[211]
522	—	2	63 18½	31 27	63 19½	31 30	1	3	[214]
311	3	1	63 18½	27 00	63 12	27 04	40	44	

TABLE 3. ANTILERITE: ANGLE TABLE
 Antlerite— $\text{CuSO}_4 \cdot 2\text{Cu}(\text{OH})_2$
 Orthorhombic; dipyramidal— $2/m \ 2/m \ 2/m$

$a:b:c=0.6867:1:0.5027$; $q_1:r_1:p_1=0.6867:1.3659:1$;		$p_0:q_0:r_0=0.7321:0.5027:1$ $r_2:p_2:q_2=1.9891:1.4562:1$					
Forms	ϕ	$\rho=C$	ϕ_1	$\rho_1=A$	ϕ_2	$\rho_2=B$	
<i>c</i>	001	—	0°00'	0°00'	90°00'	90°00'	90°00'
<i>b</i>	010	0°00'	90 00	90 00	90 00	—	0 00
* <i>a</i>	100	90 00	90 00	—	0 00	0 00	90 00
<i>h</i>	140	20 00½	90 00	90 00	69 59½	0 00	20 00½
<i>f</i>	130	25 53½	90 00	90 00	64 06½	0 00	25 53½
<i>e</i>	120	36 03½	90 00	90 00	53 56½	0 00	36 03½
<i>i</i>	230	44 09	90 00	90 00	45 51	0 00	44 09
<i>g</i>	560	50 30½	90 00	90 00	39 29½	0 00	50 30½
<i>m</i>	110	55 31½	90 00	90 00	34 28½	0 00	55 31½
* <i>n</i>	013	0 00	9 31	9 31	90 00	90 00	80 29
<i>o</i>	011	0 00	26 41½	26 41½	90 00	90 00	63 18½
* <i>q</i>	403	90 00	44 18½	0 00	45 41½	45 41½	90 00
<i>k</i>	201	90 00	55 40	0 00	34 20	34 20	90 00
<i>r</i>	111	55 31½	41 36½	26 41½	56 48½	53 47½	67 55
* <i>u</i>	221	55 31½	60 37½	45 09½	44 05	34 20	60 26½
* <i>v</i>	123	36 03½	22 31	18 32	76 58½	76 17	71 58
<i>t</i>	133	25 53½	29 12	26 41½	77 42	76 17	63 58
<i>s</i>	122	36 03½	31 52½	26 41½	71 53½	69 53½	64 43½
* <i>w</i>	142	20 00½	46 56½	45 09½	75 31½	69 53½	46 38½
* <i>x</i>	233	44 09	35 01	26 41½	66 26½	63 59	65 41
* <i>y</i>	313	77 06½	36 54½	9 31	54 10	53 47½	82 18
* <i>z</i>	121	36 03½	51 12	45 09½	62 41½	53 47½	50 57
* <i>A</i>	131	25 53½	59 11	56 27½	67 58½	53 47½	39 24½
* <i>B</i>	151	16 14½	69 05½	68 19½	74 51½	53 47½	44 42
* <i>C</i>	211	71 03	57 08½	26 41½	37 23½	34 20	74 10
* <i>D</i>	231	44 09	64 33½	56 27½	51 01½	34 20	49 37
* <i>E</i>	522	74 38½	62 13	26 41½	31 27	28 39	76 27
* <i>F</i>	311	77 06½	66 04	26 41½	27 00	24 29	78 14

Uncertain: 160, 570, 580, 015, 255, 161 of Ungemach.

* New form.

X-RAY STUDY OF ANTLERITE

by W. E. RICHMOND

A crystal of antlerite approximately 1.0 mm. long and 0.5 mm. in cross section was used to determine the lattice constants. Rotation and Weissenberg photographs were taken about the $a[100]$ and $b[010]$ axes. The measurements and calculations of these photographs give the following data:

$$\begin{array}{ll} a_0 = 8.22 \text{ \AA} & a_0:b_0:c_0 = 0.687:1:0.503 \\ b_0 = 11.97 \text{ \AA} & V_0 = 592.3; \text{ Space group } D_{2h}^{16} - Pnam \\ c_0 = 6.02 \text{ \AA} \end{array}$$

The space group was determined from the following reflections:

$$\begin{array}{l} (hkl) = \text{with all orders present} \\ (0kl) = \text{with } k+l \text{ even} \\ (h0l) = \text{with } h \text{ even} \\ (hk0) = \text{with all orders present} \end{array}$$

Content of the unit cell. The original analysis by Thaddéeff (1899), the new specific gravity (3.88), and the lattice constants were used to compute the atomic content of the unit cell. The following table summarizes these results:

	1	2	3		4	5	6
CuO	67.08	67.28	0.846	Cu	0.846	11.79	12
SO ₃	22.40	22.47	0.281	S	0.281	3.91	4
H ₂ O	10.22	10.25	0.569	H	1.138	15.86	16
Fe ₂ O ₃	0.34			O	2.258	31.45	32
CaO	0.06						
Insol.	0.48						
	<hr/> 100.58	<hr/> 100.00					

1. Analysis of antlerite from Remolinos, Chile; analyst Thaddéeff (1899).
2. Analysis calculated to 100%.
3. Molecular proportions.
4. Atomic proportions.
5. Atomic content of the unit cell.
6. Theoretical number of atoms in the unit cell.

The formula is therefore $\text{Cu}_3\text{SO}_4(\text{OH})_4$ and the unit cell contains four such molecules. The calculated density is 3.93. The formula deduced from the very similar analysis of Audrieth (1925) yields substantially the same result.

Buttgenbach (1926) described under the name heterobrochantite a mineral from Chile with the composition of antlerite but differing from that mineral in its optical properties. He also described the optical properties of an artificial copper sulphate with antlerite composition

prepared by Atanasesco (1885), and found it to constitute still a third optical variety of antlerite. Tunell (1929, p. 21) has shown that the latter distinction is based on insufficient evidence. We believe that the same is true of the supposed distinctive properties of heterobrochantite and that it also is antlerite. Mr. Jarrell, who has familiarized himself with antlerite during several years of intensive study of the Chuquicamata ores while resident there, is very definitely of this opinion. He points out in a letter to the author, "Apparently he (Buttgenbach) mistook obtuse bisectrix figures obtained on his (010) grains for flash figures. This assumption explains practically all the discrepancies between his data and the data for antlerite." Without samples of the heterobrochantite to test it is, however, not possible to state positively that it is antlerite, but Buttgenbach's evidence does not prove unambiguously that a distinction really exists.

I am indebted to Miss Alice Dowse and Mr. George Switzer for the crystal drawings.

OCCURRENCE OF ANTLERITE AT CHUQUICAMATA

Note by O. W. JARRELL

Antlerite is the principal oxide mineral of copper at Chuquicamata. It fills fracture planes that run in all directions through the altered granodiorite. The antlerite is dark green and coarsely crystalline; but, as most of the veinlets, which are up to 2.5 cm. thick, are of a cross-fiber nature, with the *c*-axes of the crystals normal to the walls of the veinlets, good terminated crystals are not common. The antlerite in these veinlets is "transported"; that is, it has not replaced directly any sulphide mineral, but has been deposited in the fractures of the rock by solutions percolating through them.

There are also not infrequently masses, up to several inches thick, of fine-grained, lighter green antlerite, found in the oxidized portions of the original sulphide veins. Besides these two principal types, there is some antlerite disseminated throughout the rock, and a little antlerite is sometimes present in masses of other minerals, such as atacamite, chalcantite, kroehnkite, or natrochalcite. However, most of the antlerite of the ore body is not associated with other copper minerals.

The occurrence of antlerite, in relation to the other copper sulphates, conforms to the results obtained by Posnjak and Tunell (1929) in their investigation of the system $\text{CuO}-\text{SO}_3-\text{H}_2\text{O}$. Their diagrams show that in a closed system, at any given pressure and temperature, the stability range of the different copper sulphates is governed principally by the concentration of the sulphate radical in the system. With decreasing concentration of SO_3 , chalcantite, antlerite, and brochantite are stable in

that order. At Chuquicamata antlerite is formed in some places directly from chalcocite; but, if there is much pyrite present in the oxidizing sulphides, antlerite is not stable in the immediate vicinity, but chalcantite, kroehnkite, or natrochalcite may form. Brochantite is rare at Chuquicamata, and the few genuine specimens that have been found have come from areas which indicate that it was stable only where the sulphate concentration was low. At Potrerillos, Chile, on the other hand, the primary mineralization was less pyritic than at Chuquicamata, and the presence of limestones (there are none at Chuquicamata) would be expected to reduce the sulphate concentration of the oxide zone. Eighteen specimens examined from Potrerillos were all brochantite.

Similar conclusions as to the dominance of antlerite over other copper sulphates at Chuquicamata have been presented by Bandy (1938, p. 693).

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CRYSTALLIZATION OF THE ROCKVILLE GRANITE

ELEANOR TATGE,

Geological Society of America, Washington, D. C.

INTRODUCTION

The Rockville granite of Minnesota is an unusually coarse-grained rock with abundant microcline phenocrysts and very little secondary alteration. In it late magmatic or deuteric effects are pronounced and, because of the coarse texture, relatively easy to study. The granite has been subjected to no recognized metamorphism beyond such deuteric replacement as occurred in direct continuation of primary crystallization. Therefore the phenomena described here are apparently uncomplicated by forces beyond those within a static body of cooling magma. The granite is an excellent subject for a paragenetic analysis of normal crystallization in a rock of simple history.

The Rockville granite lacks any suggestion of complication by replacement of a sedimentary or metamorphic wall rock. The reactions indicated, however, are so numerous and so complex that in other surroundings they might be interpreted as different from a normal igneous sequence. There is always more or less uncertainty regarding the relative period of formation of any one mineral in any particular rock and it is often difficult or impossible to understand the overlapping of crystallization periods and the formation of the same mineral at more than one stage of the solidification process. However, careful observation of a rock brings out a number of criteria which, though individually of doubtful value, together have cumulative force. Where data are insufficient to draw conclusions, at least they indicate the various possibilities. The complexity of the igneous reaction series was noted by Bowen.¹

The Rockville granite has been quarried since 1907 in the vicinity of St. Cloud, Minnesota, and it is widely used in Minnesota as architectural stone.

At the quarry the rock rises in a great dome which is exposed over at least an acre. Open joints are far apart and are somewhat irregular in direction; the most prominent strike S. 70° E. and others N. 45° E., S. 55° E., and N. 10° W. This irregularity, if joints were closely spaced, would result in much waste rock, but here, where they are spaced 20, 40, and even 100 feet apart, the irregularity is of little importance.²

¹ Bowen, N. L.: *The Evolution of the Igneous Rocks*, Chap. V, pp. 54-62, *Princeton University Press*, 1928.

² Thiel, G. A., and Dutton, C. E., *The Architectural, Structural, and Monumental Stones of Minnesota: Minn. Geol. Surv., Bull.* 25, 66 (1935).

The granite in the quarry ranges from a uniform medium-grained pink rock to an exceptionally coarse-grained rock of large pink microcline phenocrysts with interstitial biotite, hornblende, and quartz. Between these extremes the greater part of the rock is coarse-grained, uniform in composition save for sparse microcline phenocrysts which may be more than an inch in diameter. Many of the phenocrysts are oriented to suggest flow structure. Inclusions of a darker, finer-grained, gray granite a few inches long are also oriented with the flow. Microcline has apparently penetrated these inclusions, forming large phenocrysts within their borders. Several pegmatite veins of pink microcline and quartz are oriented with the inclusions. The pink microcline phenocrysts show notable zones, which are lighter in color towards the outer border. The plagioclase of the rock presents a sharp contrast to the microcline. The grains are pearly white and are crowded with dark inclusions of biotite.

The prevailing uniformity of the rock and the variety in the feldspars are shown clearly by polished surfaces on hand specimens and on Minneapolis buildings. Microcline, besides forming phenocrysts, penetrates every mineral assemblage as veins, stringers, and threads, completely anhedral. The pearly white plagioclase grains are euhedral but are splotched in the centers with abundant biotite inclusions and pink patches of microcline.

CHEMICAL ANALYSIS OF THE ROCKVILLE GRANITE*

SiO ₂	69.63	CO ₂	0.11
Al ₂ O ₃	14.83	TiO ₂37
Fe ₂ O ₃54	ZrO ₂05
FeO.....	3.53	P ₂ O ₅28
MgO.....	.83	S.....	.07
CaO.....	2.35	MnO.....	.23
Na ₂ O.....	2.32	BaO.....	.03
K ₂ O.....	4.34	Cl.....	.05
H ₂ O ⁺23	Ni, Co.....	.06
H ₂ O ⁻10		
		Total.....	99.95

* F. F. Grout and F. J. Pettijohn, *analysts*.

Measurements of minerals in half a dozen thin sections indicated the following averaged percentages:

Plagioclase.....	36.0%
Microcline.....	33.9
Quartz.....	23.3
Biotite.....	6.7
Total.....	99.9

Although the percentage of plagioclase as measured is slightly higher than that of microcline, a hand specimen shows clearly that microcline is actually more abundant. The discrepancy is due to selection among the rock chips used in preparation of the thin sections so that no slide would be entirely microcline. Hornblende occurs in the rock in aggregates of fairly large grains, but it is considerably rarer than biotite and was not encountered in the thin sections measured. The rock is a biotite-quartz monzonite, assigned to the 226 granite subdivision of the Johannsen classification.

MINERAL DESCRIPTIONS

The primary minerals of the Rockville granite crystallized slowly and in the presence of mineralizers as shown by their unusual size, the signs of resorption and recrystallization of the mafic minerals, zoning of the early plagioclase feldspar, and deuteric effects. The mineral suite includes the following, listed in approximate order of abundance:

Primary			Secondary
Essential	Characterizing Accessory	Minor Accessories	
Microcline Andesine and Oligoclase Quartz	Biotite	Albite Hornblende Apatite Allanite Magnetite Zircon Sphene Fluorite	Sericite Chlorite Sphene Epidote Zoisite Calcite Kaolinitic mineral Pyrite

Microcline. The crystals of microcline are commonly as much as 2. centimeters across, equidimensional, and are pale pink in the hand specimen. Zoning is visible to the naked eye as paler and stronger pink bands. Under the microscope it is seen that different perthite patterns characterize successive zones. Perthitic albite is evenly distributed throughout the centers and throughout the individual zones. The outer borders of many of the microcline crystals are comparatively free from albite except for widely spaced veinlets perpendicular to the edge. Between the border and the central part of the crystal is a narrow zone of closely packed albite lamellae (Fig. 6). The megascopically white zones are high in albite content, the pink ones in microcline. Against earlier crystals the outer edges of the microcline are entirely anhedral

and exceedingly irregular in detail. Intergranular spaces between the earlier crystals are filled with microcline, or to a lesser extent with quartz. The plagioclase is embayed by microcline and is spotted with microcline inclusions.

Andesine and oligoclase. Plagioclase feldspar occurs in two sharply defined varieties, an early, euhedral andesine-oligoclase, and a late, perthitic or bordering albite, which will be described below. The larger plagioclase crystals examined under the microscope were as much as 3 millimeters across, and hand specimens show considerably larger grains, some more than a centimeter in length. However, these are commonly if not always aggregates. The centers—earliest portions— of the crystals are andesine, grading to oligoclase toward the edges, or even to albite. The edges may be bordered in part by the late albite mentioned above, which is easily distinguished from the early main part of the crystal by the Becke line; zoning in the early crystal is too gradual for a contact line to be perceptible. Smaller crystals of the early plagioclase are of oligoclase. These formed at the time the oligoclase border was growing on the larger, first-formed crystals. The larger crystals contain euhedral inclusions of the accessory minerals as well as introduced microcline and quartz. An even distribution of tiny biotite inclusions of uniform size is characteristic and suggests that the biotite crystals had reached this size at the time the plagioclase crystal started to grow, were caught up and surrounded by plagioclase, and were thus prevented from reaching the larger size of the neighboring biotite grains. Perhaps the force with which plagioclase crystals grow is sufficiently less than that of microcline so that the plagioclase grows around foreign crystals, while the enlarging microcline grains push them aside. Many of the andesine crystals are marked by a pattern of small blocks with edges oriented with and across the albite twinning. The pattern is plainest toward the centers of the crystals. There are three different types: first, in some areas quartz and microcline included in the andesine form the rectangular blocks. Second, in other areas the blocks are of andesine but have a slightly different extinction angle from the surrounding crystal. A faint Becke line shows that these blocks have a slightly lower index than that of the surrounding feldspar, and so are slightly more sodic (Fig. 1). Third, the pattern also results from blocks in which the albite twinning gives way abruptly to pericline twinning at right angles. The alternation of blocks twinned in the two directions produces an effect more truly like a chessboard than the "chessboard albite" pictured by Olaf Andersen³ or by G. H. Anderson⁴ which show interrupted twinning with the

³ Andersen, Olaf, The genesis of some types of feldspar from granite pegmatites: *Norsk Geologisk Tidsskrift, Bull.* 10, 116–207, pl. 4, fig. 1 (1928).

twins running in the same direction. In some crystals of the Rockville andesine the block pattern shows up because of interrupted albite twinning, but such interrupted twinning does not seem to be due to enlargement of perthite veins by replacement as postulated by Olaf Andersen⁵ for albite. The several types of block pattern may occur individually in any one andesine crystal or collectively.

The plagioclase crystals show rounded edges indicative of corrosion by microcline where the two minerals are in contact, with rims of clear or myrmekitic albite. At intervals microcline has embayed the plagioclase or penetrated it in branching tree-like forms; and it has cut off sections of plagioclase from the main crystal altogether, so that the pieces, corroded and rimmed, form islands optically continuous with the "mainland" crystal. Antiperthitic patches of microcline in the plagioclase are perhaps cross sections cut through embaying arms or stringers of microcline. All degrees of microclinization occur from minute square inclusions widely spaced to large patches of microcline shouldering each other, so crowded that only shreds of plagioclase lie between. Within the larger plagioclase crystals antiperthitic microcline in patches of unusual size has reacted with the surrounding plagioclase, embaying and corroding it in the same fashion that it has attacked plagioclase crystal faces from without.

Quartz. Quartz is of the usual granitic variety showing long rows of pin-point liquid and gas bubbles. Microcline and quartz crystallized contemporaneously, each embaying the other. Although there is much less quartz than microcline in the rock, they replaced plagioclase and hornblende in identical patterns. Both quartz and microcline form bays in the plagioclase; blocks of quartz are included in the interior of corroded andesine crystals as well as blocks of microcline; and one fair-sized corroded plagioclase island was observed in a sea of quartz, paralleling the islands occurring in microcline. Quartz is associated with biotite as inclusions in the interior of the crystals, as blebs intergrown in the corroded fringes at the ends of the biotite grains, and as small crystals intimately intergrown with tiny magnetite grains in corrosion pockets along the edges of the biotite.

Biotite. The grains of biotite are about the same size as hornblende grains—the largest about 2 millimeters long and slightly narrower; pleochroism $Y = Z$ deep brown, X slightly greenish-yellow. Inclusions of zircon, apatite, magnetite, pyrite, and sphene are plentiful. The ends of many biotite crystals are corroded. They may be fringed and chloritized,

⁴ Anderson, G. H., Granitization, albitization and related phenomena in the northern Inyo Range of California-Nevada: *Geol. Soc. America, Bull.* **48**, 1 74, pl. 4, fig. 3 (1937).

⁵ Andersen, Olaf, *ibid.*, 170.

with quartz blebs and magnetite intergrown at plagioclase or hornblende contacts; or they may be rounded and edged with magnetite at quartz contacts. Although the chloritized fringes on the biotite occur between biotite and plagioclase, they are best developed against and penetrating hornblende. They are composed of chlorite oriented with the cleavage of residual biotite plates and interspersed with sphene and epidote. At the base of the fringe small quartz blebs and fine-grained magnetite outline the solid biotite core. Several of the biotite grains show signs of corrosion at the sides as well as at the ends. Rounded pockets eaten into the biotite are filled with a more or less regular intergrowth of tiny magnetite and quartz crystals, or with tiny rows of magnetite in a ground-mass of plagioclase optically continuous with an adjoining crystal. Distortion of biotite laminae by bending and fracture is common. Small biotite grains may be included in hornblende crystals in parallel intergrowth (Fig. 8). The irregular outline of the biotite and the occurrence of hornblende in the cleavage cracks, as well as the poorly defined character of the hornblende cleavage, suggest the replacement of biotite by hornblende. Such replacement is not uncommon in rocks crystallizing with mineralizers.

Hornblende. Hornblende occurs sparingly in the Rockville granite in crystals of moderate size, about a millimeter across, usually three or four grouped together. The crystals are not sharp and clean-cut but have irregular edges and cleavage, slightly rounded corners, and a cloudy appearance. The pleochroism of most crystals is *Z* deep blue-green, *Y* bright green, *X* greenish-yellow, but the deep blue-green of the *Z* direction is splotched with patchy areas and vein-like traces of greenish blue, suggesting a slightly more sodic composition. Besides the early accessories, biotite, quartz, and microcline form inclusions (Figs. 7, 8). Much of the hornblende immediately surrounding quartz and microcline is blue.

Early accessories. Of the early accessories, apatite and zircon occur included in magnetite; all three minerals are widely distributed in euhedral grains usually 0.01 to 0.1 millimeter across. Apatite, the most abundant, is scattered uniformly throughout the rock, the largest crystals measuring 1.25 by 0.03 millimeter. Zircon and magnetite usually form inclusions in biotite and hornblende. Zircon is plentiful in well-formed prisms surrounded by dark halos in the biotite. Magnetite occurs in two associations, chiefly as an early accessory included in biotite in grains somewhat larger than the zircon prisms, also as fine-grained aggregates marginal to biotite, a by-product of corrosion. Sphene is chiefly secondary, associated with chlorite, but occasional grains of fairly regular outline included in biotite may be primary. Allanite is in euhedral

crystals of unusual size—1 or even 2 millimeters long. The crystals are slightly pleochroic, light to orange brown, showing zonal growth and occasional twinning. A trace of purple fluorite is included in one allanite grain; white fluorite in minute crystals occurs scattered through the rock.

Albite. The late plagioclase, albite, is distributed as perthitic intergrowth in microcline and as borders on early plagioclase crystals, especially at microcline or quartz contacts. Three types of perthite as described by Olaf Andersen⁶ were recognized, one similar in pattern to his "vein perthite," a second to his "film perthite," the third showing the fine texture of his "string perthite." At intervals narrow albite veins coalesce to form wider ones which might correspond to his "patch perthite," but the appearance is neither common nor marked in character. Little twinning has been observed in any of the perthitic albite. Albite veins are about 0.01 to 0.03 millimeter wide, forming a regular pattern of subparallel streaks 0.1 millimeter apart across microcline. In detail the outline of the streaks is far from regular; alternate thickening and thinning with coalescing and parting of tiny stringers along the sides is the rule. The regular distribution of the veins may be due to replacement of microcline by albite along contraction cracks as suggested by Olaf Andersen.⁷ For vein perthite in plutonic rocks Alling⁸ accepts Andersen's conclusions, considering the process deuteric—that is, late magmatic. Between the veins tiny lenses of albite forming film perthite are common. Occasionally these tiny lenses occur in patches, the veins giving way to the lenses for a short interval. The outlines of the little lenses are smooth and uniform. In the coarser varieties the lenses may be more than 0.1 millimeter long and perhaps 0.025 millimeter apart, in a patch about a millimeter across, whereas in the finer varieties the lenses can scarcely be distinguished with the 4-millimeter objective, and probably some are submicroscopic. All appearance of grating structure in the microcline is lacking in these areas. The finer lamellae of albite are unquestionably due to exsolution.⁹

Late albite occurs also as rims, chiefly on earlier plagioclase grains, and is most pronounced at microcline or quartz contacts. The earlier plagioclase is corroded and embayed, its corners rounded, then built out again by albite. The albite is very easily distinguished from the andesine or oligoclase because of its lower index and higher birefringence, and because it is much less sericitized (Figs. 3 and 4). Some albite is added

⁶ Andersen, Olaf, *ibid.*, 149–150.

⁷ Andersen, Olaf, *ibid.*, Chap. II, 121–145.

⁸ Alling, H. L., Perthites: *Am. Mineral.*, 17, 61 (1932).

⁹ Alling, H. L., Plutonic perthites: *Jour. Geol.*, 46, 163 (1938).

to the early plagioclase crystals in continuance of the original twinning pattern but with a slight difference in extinction angle. Around other plagioclase crystals the albite rim is irregular and myrmekitic, and the twinning pattern is absent. Small plagioclase crystals in microcline may have albite rims of varying widths (Figs. 3 and 4). There may be more rim than core, or the core so far corroded and sericitized that it is no longer recognizable as plagioclase. It is not only on early plagioclase that the deuteric albite has crystallized, but rows of tiny albite crystals may be seen along the line of contact between two microcline crystals. These seem to have grown into the microcline from both sides of the contact, spreading in fan-shaped units, a few containing myrmekitic quartz intergrowths.

Many fine examples of myrmekite occur in the albite rims. Commonly myrmekitic albite forms lobes spreading into the microcline with vermicular quartz in a dendritic pattern; or the quartz blebs may lie in a more or less parallel row in a fairly narrow albite rim, branching slightly towards the microcline somewhat like a row of cactus plants; or the quartz blebs may be very short, almost equidimensional, and scattered locally in a broad albite rim with albite twinning passing through the whole area except where interrupted by the quartz.

Secondary minerals. The granite is relatively fresh and unaltered but shows a few signs of hydrothermal action, chiefly on the biotite and calcic plagioclase. Many grains of biotite have been chloritized along the cleavage planes; a few whole crystals, mostly small ones, have been turned to chlorite. The chlorite is accompanied by sphene and some epidote, commonly along cleavage cracks. The chief alteration product of plagioclase is sericite, accompanied by considerable epidote and zoisite. Allanite also contains disintegration products, which may have resulted from hydrothermal alteration. Pyrite occurs associated with magnetite. A kaolinitic mineral in small amounts is widespread.

HISTORY OF CRYSTALLIZATION

Perhaps the earliest evidence of the behavior of the Rockville magma is shown by scattered xenoliths of a gray rock which were partly digested by the including magma and wholly permeated by alkalic fluids. Crystallization of the magma may have started before the xenoliths were incorporated. The coarse texture of the Rockville granite suggests that its solidification was a slow process with normal crystallization accompanying the falling temperature, although there are evidences of corrosion, resorption, and replacement due to the abundant mineralizers, such as the corrosion of calcic plagioclase, and the slight replacement of biotite by hornblende. The microcline phenocrysts did not result from

early crystallization as in an extrusive porphyry but were among the last of the magmatic minerals to form. The sequence of crystallization is on the whole a normal magmatic sequence; the texture of the rock is granitoid; the texture of the individual minerals indicates free crystallization from a liquid for the greater part of them. Observation of paragenetic relationships suggests the following order of crystallization:

PRIMARY.

Early magmatic

Zircon and apatite

Magnetite

Sphene

Allanite (and purple fluorite?)

Biotite

Andesine

Oligoclase

Late magmatic or deuteric

Magnetite

Microcline, albite, and quartz

Hornblende

White fluorite

SECONDARY (IN MINOR AMOUNTS).

Sericite and calcite; chlorite and sphene; epidote and zoisite

Pyrite

Kaolinite

There is here at least no evidence against the early crystallization of euhedral minor accessories. Zircon and apatite apparently formed at about the same time. Both are included in magnetite. The early magnetite grains are rough in shape, probably corroded by the magma at about the time of growth of the biotite and allanite around them. At this stage some of the sphene of the rock may have formed, for there are a few compact grains included by fresh, unaltered biotite. These, although not definitely euhedral, are yet unlike the straggly anhedral grains associated with secondary products in the rock. Allanite grains both large and small are strictly euhedral.

Biotite was the first of the essential minerals to crystallize. Some of the crystals while still small were surrounded by plagioclase, the next mineral in sequence, forming characteristic minute inclusions. The first plagioclase to crystallize in permanent form was andesine. The large size attained by the crystals is evidence of the great length of time involved in their growth and the presence of the mineralizers. At first they were not abundant. They probably started fairly early, when the biotite crystals were as yet tiny specks in the enveloping magma. As the andesine crystals grew many of the tiny biotite crystals were included

as well-distributed, equidimensional grains. As the andesine continued to crystallize, the calcium-sodium ratio in the remaining magma became gradually lower, as shown by the slight but progressive change in the extinction angle of the albite twinning lamellae toward the borders of the crystals, indicative of a correspondingly slight but progressive change in composition to the more sodic plagioclase, oligoclase, or even to albite. As the large plagioclase crystals grew, new centers of plagioclase crystallization were continually forming. From these grew smaller crystals of higher soda content. Therefore, in general the smaller and more sodic plagioclase crystals formed late. Some slight corrosion of biotite crystals took place where plagioclase came in contact with it, for there are pockets of magnetite-plagioclase intergrowth at such contacts.

Late in the primary crystallization sequence the highly alkalic rest-magma became corrosive. Deuteric resorption, recrystallization, and replacement are characteristic of this stage. Microcline and quartz penetrated the crystal boundaries of plagioclase, there solidifying in corrosion channels. Biotite was corroded, and small crystals of residual magnetite became massed along the ends of the grains or in pockets of quartz-magnetite intergrowth in the ends or sides of the grains. A little of the biotite, and some of the microcline which had begun to form, were replaced by hornblende of high soda content, its lime perhaps derived from the corrosion of plagioclase. The plagioclase crystals were corroded from without and were replaced within. Corners were rounded, edges embayed, and whole blocks were separated to form islands later in a microcline sea. Long stringers of microcline worked their way into the interior of plagioclase grains. By this time the magma was sufficiently cool and hydrous so that the calcic centers of plagioclase grains were none too stable. A pattern of small blocks of alternate albite and pericline twinning developed in the interior of many andesine crystals, producing a checkered effect. Other blocks suffered substitution of calcium by sodium so that they are formed of a plagioclase of a distinctly lower index of refraction and slightly different extinction angle. Still other blocks have been dissolved away altogether and microcline, or here and there quartz, substituted. The block pattern is best developed near the centers of the largest plagioclase grains, that is, where the calcic composition makes them least stable. A sequence in the development of the pattern is suggested by its occurrences. Probably the substitution of small amounts of soda was the first alteration. In many of the smaller crystals this is the only alteration. With further attack by rest-magmatic fluids came the crystallographic readjustment marked by the checkerboard twinning. Complete corrosion of the more susceptible cross-twinned or sodic blocks with consequent filling in by microcline or quartz followed. This order

was by no means sharply defined. In the same crystal the various steps in the sequence overlapped. In the smaller, more stable crystals blocks of sodic plagioclase, quartz or microcline were slower to develop and less conspicuous finally. Many crystals show only the soda block pattern, others only small and widespread antiperthite blocks. Even in crystals with much reorganization of centers, the more sodic borders are affected little if at all.

The crystals above described formed a very loose mesh, in part were actually suspended in the highly alkalic rest-magma. In this, microcline crystals grew with less abundant quartz. At higher temperatures the microcline crystal lattice may have contained potassium and sodium in equivalent interchangeable positions. Having plenty of time, space, material, and temperature, the microcline grains grew to their observed great size. Upon cooling, the sodium and potassium ions were no longer able to hold identical positions, and the albite unmixed from the solid solution to form strings and films of the characteristic exsolution perthites. Contraction cracks developed on further cooling, making passageways for albitization to form vein perthites. Contraction cracks developed in the simultaneously forming quartz also, and were healed by later quartz, their places marked by rows of microscopic liquid and gas inclusions caught in them.

Among the latest and most widespread of the deuteritic phenomena of this last stage in the process of primary crystallization was albitization. The solidification of microcline in the alkalic rest-magma used up the potassium but left a very sodic, mobile solution that before the microcline was completely crystallized was providing molecules of albite which attached themselves most readily to the corroded early plagioclase projecting into the microcline, and which filled contraction cracks in the microcline as fast as they appeared, thus forming vein perthite. Where the microcline was solid against the early plagioclase, albite continued to grow, replacing the microcline bit by bit, penetrating it in fan-shaped projections, including bits of silica here and there which solidified as vermiform streaks in myrmekite. Albite not only attached itself to early plagioclase, but grew along the boundary between adjoining grains of microcline, and, as myrmekite, even developed along the edge of a biotite-magnetite complex. Rare fluorite crystals possibly indicate a final touch of pneumatolysis.

The only metamorphism shown by the Rockville granite is a slight amount of hydrothermal alteration. Hydrothermal solutions may have carried foreign elements into the rock. However, most of the elements involved in the secondary minerals might easily have come from their immediate neighborhood. The formation of chlorite from biotite released

potassium to form sericite from andesine. Calcium thereupon released from the andesine was used in the formation of sphene, calcite, and zoisite, and, with iron from biotite, formed epidote. Sphene derived titanium from the biotite upon its change to chlorite. Pyrite is found adjacent to, even included by magnetite, and probably derived its iron thence.

The shreds of kaolinitic mineral were probably the last to form in the Rockville granite, a result of the leaching of alkali during weathering.

CONCLUSION

Summarizing, the Rockville granite is a magmatic rock the coarse texture of which simplifies the study of its paragenesis. Its crystals formed, in general in the normal order, as follows: (1) minor accessories; (2) biotite and plagioclase; (3) microcline, quartz, hornblende, and albite, with accompanying deuteritic phenomena; (4) hydrothermal minerals such as chlorite, sericite, titanite, and epidote.

ACKNOWLEDGMENTS

The work was undertaken at the suggestion of Dr. F. F. Grout and chiefly carried out with a microscope kindly loaned by Dr. James Gilluly. Appreciation is here expressed to them and to many others for assistance, advice, and criticism of the manuscript.



FIG. 1. The center of an andesine crystal contains small rectangular blocks (white in the photograph) of slightly more sodic andesine. The albite twinning passes through them without interruption. Crossed nicols; $\times 93$.

FIG. 2. A small portion of a large andesine crystal here shows blocks of pericline twinning (nearly vertical) interrupting the albite twinning (horizontal). Crossed nicols; $\times 97$.

FIG. 3. Albite borders on minerals in contact with microcline were formed partly by replacement, partly by addition. Here an andesine crystal completely surrounded by microcline shows a white albite border around the sericitized gray core. Crossed nicols; $\times 87$.

FIG. 4. The albite rim (grayish) is wide and twinned in continuation of the albite twinning of the sericitized andesine core. Crossed nicols; $\times 85$.

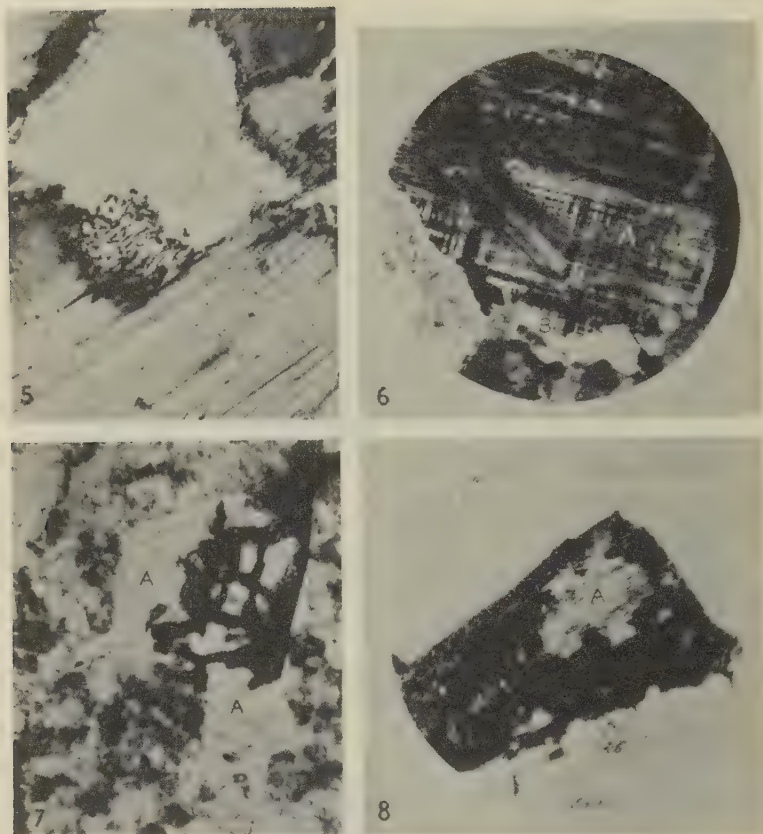


FIG. 5. The rest-magma attacked biotite grains forming pockets of magnetite-quartz intergrowth. Here the intergrowth (center) is lying between biotite (below) and quartz (above). Ordinary light; $\times 50$.

FIG. 6. Microcline crystals grew very large between grains of earlier crystals, perhaps pushing them aside. The end of a large grain is pictured showing a prominent zone at A interrupting the twinning. It is composed of fine albite films barely discernible in the picture, elongated almost horizontally, not parallel to the zone marked A, but rather to the NE-SW twinning direction. B marks the boundary of the microcline crystal against a small plagioclase grain. Following this contact, the irregular, anhedral character of the microcline boundary is observed. Crossed nicols; $\times 17$.

FIG. 7. Microcline (A) is being replaced by hornblende (black). The microcline is optically continuous. Ordinary light; $\times 49$.

FIG. 8. The biotite remnant (A) is enclosed in hornblende which has replaced the greater part of the original biotite crystal. Hornblende occurs along cleavage cracks in the remnant. Ordinary light; $\times 37$.

Photographs 1 and 2 were taken by George Tunell and C. J. Ksanda whose kindness is much appreciated.

THE IDENTITY OF DAKEITE AND SCHROECKINGERITE

RADIM NOVÁČEK, *Charles IV University, Praha, Czechoslovakia.*

Schroëckingerite was described in 1873 by A. Schrauf (15) as a new hydrated uranium-calcium carbonate, found at Jáchymov (Joachimstal). According to the original description and all subsequent references which only repeat the data of Schrauf (3, 4, 9, 10, 14, 18), and according to the article by Baron J. v. Schroëckinger (16), schroëckingerite consists of small six-sided scales with a bright yellowish-green color, pearly

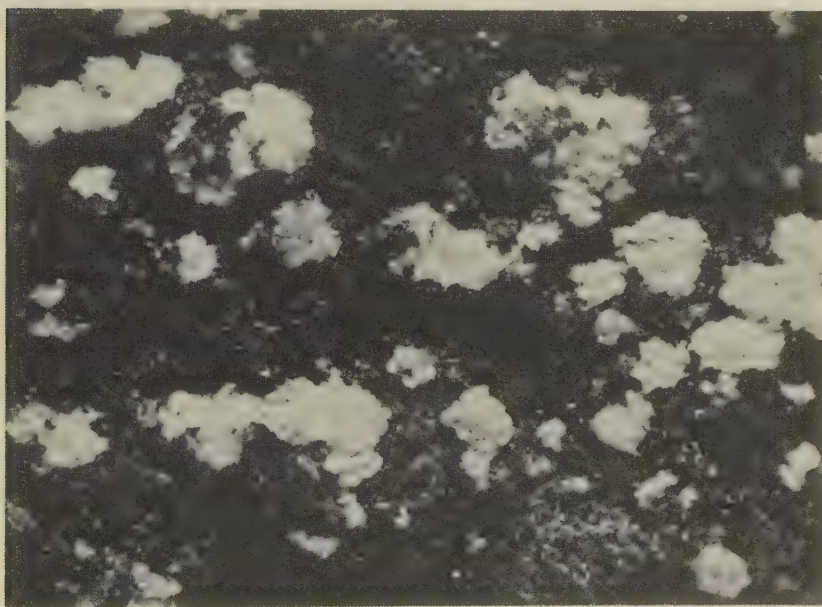


FIG. 1. Schroëckingerite on uraninite from Jáchymov. $\times 8$.

luster, and perfect mica-like cleavage. The scales are about 1 mm. in diameter and form globular and flaky groups on uraninite (Fig. 1). Schrauf describes the six-sided scales as orthorhombic combinations of (001) with (110) and a pinacoid, designated by him as (100); the angle between the pinacoid and the prism is $58\frac{1}{2}^\circ$. The axial plane is perpendicular to the pinacoid. No further data are given.

Schrauf made only a qualitative analysis of the new mineral and found U, CO_2 , H_2O , a small quantity of CaO and traces of $\text{SO}_4^{''}$; the loss on ignition ($\text{CO}_2 + \text{H}_2\text{O}$) was given as 36.7%.

Since the original description all the later references to schroeckingerite only repeat the statements of Schrauf. The first new determinations of the optical properties of schroeckingerite are found in Larsen's tables (6, p. 131; 7), determined on specimens from the Roebling collection. The writer adds that "A number of other species labeled 'schroeckingerite' were examined, but they proved to be uranothallite, or some other uranium mineral."

But if we compare Larsen's description ("... green-yellow coatings of minute, prismatic crystals..." "... prismatic crystals with monoclinic symmetry and cleavages (010) very perfect, and (100) perfect. It shows lamellar twinning (100). $X=b$ and $Z \wedge c = 41\frac{1}{2}^\circ$ ") with the original paper of Schrauf, we find that neither the crystal form nor the optical properties agree with the original schroeckingerite. In my paper "Study on some secondary uranium minerals" (11), and in later notes on uranium minerals (12, 13), I have pointed out the similarity of Larsen's data on the supposed schroeckingerite with the optical properties of the new mineral β -uranotile, chemically identical with uranotile or uranophane.*

This statement by Larsen in his tables changes all determinations of "schroeckingerite" published since that date. The schroeckingerite described by Miss E. J. Armstrong (2) from Bedford, N. Y., and probably the mineral from Spruce Pine, Mitchell Co., N. Carolina, labeled as schroeckingerite (Brit. Mus. of Nat. Hist., London, No. 191, B. M. 1929), are β -uranotile. Special data for these minerals and on the β -uranotile from Wölsendorf in Bavaria are given by V. Steinöcher and the writer in the following article (17).

Up to the present time it is impossible to make a complete quantitative analysis of a positively determined schroeckingerite. The fine specimens of schroeckingerite in the Národní Museum and in the Mineralogical Institute of Charles IV University, Praha, and in the Naturhistorisches Museum of Vienna (Schrauf's original specimens) cannot furnish a sufficient quantity, even for a microchemical quantitative analysis, especially for the determination of carbonic acid.

While I was preparing a specimen of schroeckingerite for an optical examination and for at least a partial analysis, there appeared in this Journal, in 1937, a description of a new mineral dakeite, from Wyoming, by Messrs. Larsen and Gonyer (8). By comparison of the properties of both minerals, I reached the conclusion that the two are identical, as may be seen from the following table:

* In the Abstract of my paper (11), published in *Am. Mineralogist* (1) read β -uranotile instead of α -uranotile.

	SCHROECKINGERITE	DAKEITE
Crystals:	hexagonal, micaceous plates	micaceous plates
Cleavage:	basal perfect	basal perfect
Color:	yellow to green-yellow	green-yellow
Pleochroism:	$X(\alpha)$ = colorless, or very pale yellow $Y(\beta)$ and $Z(\gamma)$ = pale greenish-yellow	X = very pale yellow Y and Z = pale greenish-yellow
$X(\alpha)$	1.496	1.489 ± 0.002
$Y(\beta)$	1.539–1.545	1.542 ± 0.001
$Z(\gamma)$		
Optically:	negative	negative
$2V$ (for Na-light):	0° – 25° (rarely to 40°)	5° (Larsen); 5° – 15° (Nováček)
Dispersion:	not perceptible	not perceptible
Luminescence in ultraviolet light:	bright yellowish-green	bright yellowish-green
Specific gravity:	2.515	2.51

Also from the chemical point of view both minerals are in agreement as shown in the following table:

(I) Dakeite analyzed by Mr. Gonyer.

(II) My partial analysis of schroeckingerite from Jáchymov (4 mg. and 2 mg. of material).**

(III) Theoretical values for the composition $3\text{CaO} \cdot \text{Na}_2\text{O} \cdot \text{UO}_3 \cdot 3\text{CO}_2 \cdot \text{SO}_3 \cdot 10 \text{H}_2\text{O}$ as it is interpreted by Larsen and Gonyer (8).

	I DAKEITE	II SCHROECKINGERITE	III THEORET. COMPOSITION
CaO	18.31%	19.1%	18.9%
Na ₂ O	7.31	not determined	6.9
UO ₃	30.27	32.4	30.3
CO ₂	13.71	not determined	14.8
SO ₃	9.61	9.1	8.9
H ₂ O	19.95	20.2	20.2
Insoluble	1.06	0.4	—
	100.22	—	100.0
Loss on ignition (Nováček)	34.67%	36.04%	
Loss on ignition (Schrauf)	—	36.7%	

** The methods of analysis are described in greater detail in my paper, 1936 (11, p. 3–5): uranium was determined in acetate solution as oxychinolate, calcium as oxalate and the sulphate as barium sulphate. The dehydration was carried out in a platinum micro-crucible after it had been shown that the partially dried mineral is not hygroscopic; the dehydration was continued in an electric furnace until a temperature of 345°C . was reached.

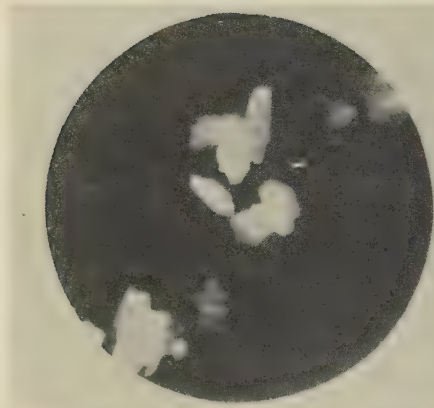


FIG. 2. Schroeckingerite from Jáchymov. Photomicrograph of six-sided crystals and their cross sections. $\times 47$. Crossed nicols.

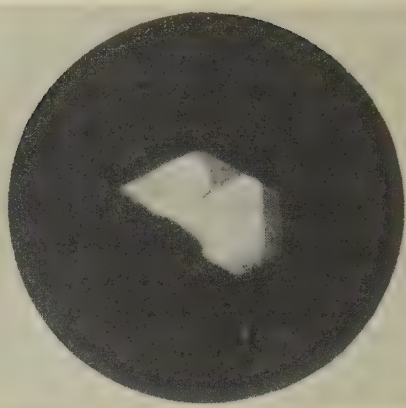


FIG. 3. Schroeckingerite from Jáchymov. Photomicrograph of a fragment of a six-sided scale parallelly intergrown with smaller scales. Minute black inclusions visible. $\times 87$. Crossed nicols.

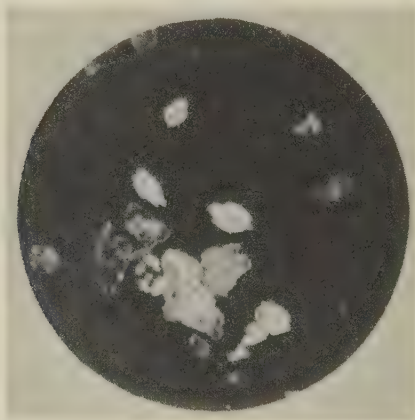


FIG. 4. Photomicrograph of dakeite from Wyoming. $\times 47$. Crossed nicols. The scales do not have the six-sided outline like schroeckingerite.

It is evident that also chemically there is no doubt about the identity of both minerals, especially since sodium has been found present in the schroeckingerite from Jáchymov. The dehydration curves for schroeckingerite and dakeite are exactly parallel (Fig. 5). The smaller content of water in dakeite (I stated it as 18.95% at 345°C. whereas Mr. Gonyer has determined it as 19.95%, and the theoretical value is 20.2%) may be explained by the fact that a considerable part of the H_2O is expelled at a very low temperature, as is shown in the diagram.

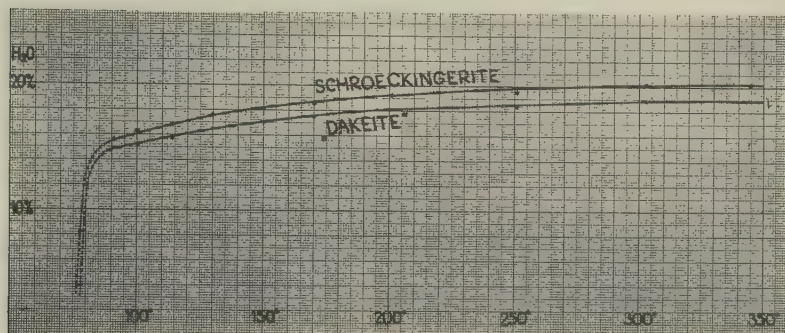


FIG. 5. Dehydration diagram of schroeckingerite from Jáchymov and dakeite from Wyoming. Except for the small difference in the total amount of water, the complete conformity of both curves is evident.

The higher content of uranium in the mineral from Jáchymov is caused by the presence of small dark inclusions of uraninite (?); it was impossible to eliminate them entirely from the analyzed mineral.

It is interesting to note that Schrauf (like Mr. Larsen originally with dakeite, cf. 5) did not indicate the presence of sodium. The extraordinary sensitivity of the flame test for sodium accounts for this omission. Less easily explained are Schrauf's data on the small amount of calcium and on "hardly provable traces" of sulphate. I have been able to demonstrate on the original schroeckingerite material of Schrauf (Wien, Naturhist. Mus., sample Aa 6740) that both the reactions for Ca and SO_4 are quite distinct when the microchemical test is employed.

The statement of Schrauf that the angle (100):(110) is $58\frac{1}{2}^\circ$, may be an error of observation, quite possible on scales of micaceous character like those of schroeckingerite. I have not been able to find distinct differences from 60° on the six-sided scales. There exists the possibility that schroeckingerite (or dakeite) is hexagonal and that the observed biaxial character (axial angle $2V=25^\circ$, in a few cases even 40° in schroeckingerite, 5° in dakeite, after Larsen) is an anomaly; I have observed greater values, up to 10 – 15° , on dakeite from the University's collection.

According to the kind communication of Doctor A. Scholz (Regensburg) who has studied schroeckingerite from the collections of the University Mineralogical Department at Bonn and from the Naturwissenschaftlicher Verein of Nurnberg, labeled "zippeite," he found several small euhedral crystals, on which he was able to determine differences of about 2° from the value of 60° . The locality of one sample was Jáchymov, of the other Johanngeorgenstadt.

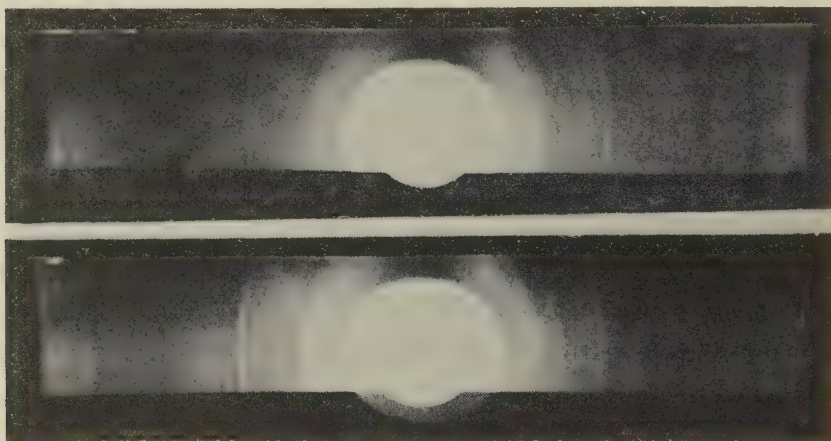


FIG. 6 *a.* (above) Debye-Scherrer diagram of schroeckingerite from Jáchymov.
b. (below) Debye-Scherrer diagram of dakeite from Wyoming.

The Laue-diagrams made by Professor F. Ulrich and Mr. V. Schön on the schroeckingerite from Jáchymov are not sufficiently distinct to permit definite conclusions. The imperfect quality of the Laue-diagrams is caused by smaller scales of schroeckingerite, parallelly intergrown on practically every large individual crystal. The Debye-Scherrer-diagrams of schroeckingerite (Fig. 6 *a*) and dakeite (Fig. 6 *b*) confirm fully the identity of both minerals.

All the data given above prove satisfactorily that the schroeckingerite from Jáchymov (Joachimstal), described though incompletely by Schrauf, and the dakeite from Wyoming, described by Messrs. Larsen and Gonyer, are identical. The priority of the name schroeckingerite is apparent.

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ON β -URANOTILE

V. STEINOCHEK AND R. NOVÁČEK, *Charles IV University,
Praha, Czechoslovakia.*

(Optical investigations by V. Steinocher, chemical analyses
and general description by R. Nováček.)

In 1935 the name β -uranotile was given by R. Nováček (7) to a new mineral from Jáchymov (Joachimstal) which was chemically identical with uranotile (=uranophane) and possessed the formula $\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$, but was distinctly different in physical, and especially in optical properties. It has been shown that the optical data of the new mineral agree with those given by Larsen and Berman (5, 6) for schroeckingerite. Evidently Larsen determined the optical constants on a sample of β -uranotile mixed with carbonates, and therefore regarded it as a carbonate (schroeckingerite). The true schroeckingerite is described in detail and its identity with dakeite shown in the preceding article by R. Nováček (10).

The data in Larsen's tables have caused the occurrences of two β -uranotiles from localities in the United States to be described as schroeckingerite. In 1935, Miss E. J. Armstrong reported this mineral as occurring in minute needles in the fissures of a pegmatite at Bedford, N. Y., and likewise the specimen from Spruce Pine, Mitchell Co., N. Carolina, in the British Museum of Natural History, London (No. 191, B. M. 1929) was labeled schroeckingerite. Both minerals are β -uranotile.

A third new locality of β -uranotile (besides the original locality of Jáchymov) is the well known fluorite occurrence at Wölsendorf, Bavaria. From this place the first crystallized uranotile was described by E. Bořický in 1870 (3), and not long ago A. Schoep and A. Scholz discovered (12) an unusual association of uranium minerals: uraninite, ianthinite, kasolite, fourmariérite, parsonsite, dewindtite, becquerelite and schoepite. At the end of their paper the writers state, that beside the above-named minerals, which they were able to identify definitely, they found on one specimen a small quantity of an unknown mineral, and record approximately its optical properties. As will be mentioned later, this mineral likewise has been shown to be β -uranotile.

In the present paper are given the optical and, where it has been possible, also the chemical data of the β -uranotile from the named localities.

The optical investigations have been carried out on an universal stage, modified according to Emmons, with five axes. The large dispersion of the extinction directions and high refraction made the use of monochromatic light necessary. This was produced by means of filters, so combined

as to give the maximum amount of transmitted light with the greatest possible approximation to the required wave length. The filters were checked in advance spectroscopically.

The refractive indices were determined by means of the special Leitz arrangement in combination with the universal stage. This is a glass hemisphere with a small cavity of hemispherical shape into which the investigated mineral is placed and covered with an immersion liquid of a refractive index a little higher than that of the mineral. Upon heating by means of an electric current the refractive indices of the mineral and of the surrounding liquid become equal and the value determined from the angle of total reflection, which is measured directly on the stage. A more detailed description of this method is given by Rinne and Berek (11). According to the statement of Leitz, the accuracy of the determination of the refractive indices is ± 0.002 . Naturally it is necessary, as we have done in our investigations, to take a mean value of several measurements.

Quantitative chemical analyses could be made in only two instances, by microchemical methods on minute quantities. SiO_2 was determined by treatment with nitric acid, evaporating several times to dryness, filtering and igniting in an electric furnace. The ignited and weighed impure silica was evaporated with hydrofluoric acid as SiF_4 and the residue subtracted from the original weight of the impure SiO_2 . The uranium was precipitated from the acetate solution and weighed as oxychinolate (oxine); calcium was determined as the oxalate. The more detailed data on the analytical procedure are given in the paper of Nováček (7, p. 3-5), where also more complete references to the literature are included (Hecht, Schwarz-Bergkampf, etc.).

β -URANOTILE FROM JÁCHYMOV (JOACHIMSTAL)

The β -uranotile from this original locality is described in detail in the papers of Nováček (7, 8, 9), where also a chemical analysis is given. The data are here briefly summarized, together with a more complete report on the optical properties.

β -uranotile from Jáchymov usually forms coatings on uraninite. The minute needles, generally shorter than 1 mm., are of yellowish-green or more rarely of a pure yellow color and include minute black grains, perhaps of uraninite. The needles are either intergrown with the matrix or are grouped in fan-like and radial tufts in cavities, from which single crystals may be relatively easily isolated. The needles of β -uranotile are less elongated than those of normal uranotile from Jáchymov and other localities (length to breadth = 5:1, 3:1, etc.); sometimes their shape is more tabular.

The goniometrical investigations (Nováček (7), p. 26) could not be carried out accurately because of the imperfect character of the crystal faces. The microscopical data, given below, are more reliable. Nevertheless, even these imperfect measurements prove the monoclinic symmetry of the β -uranotile, with a perfect clinopinacoidal cleavage and with the angle β nearly equal to 90° . In the original description by Nováček (7) the value of ρ (001) is given as 2° , or $\beta = 92^\circ$. The microscopical measurements by Steinocher show a greater inclination, $\beta = \text{about } 94^\circ$. Of the domatic forms, only one orthodome face, with the angle $\rho = 48^\circ 36'$, has been established on the goniometer.

The β -uranotile crystals from Jáchymov are almost without exception twinned parallel to the orthopinacoid (Figs. 1, 2, 4). A more detailed description of the twinning is given later.

The density was determined by suspension in Clerici's solution and found to be 3.953.

V. Billiet (2) investigated the structure of β -uranotile crystals roentgenometrically, but only Debye-Scherrer diagrams could be made, so that a conclusion concerning the crystal structure of this mineral is not possible.

The quantitative chemical analysis is given in the papers quoted by Nováček (7, 8). The result agrees closely with the theoretical formula for normal uranotile, $\text{CaO} \cdot 2\text{SiO}_2 \cdot 2\text{UO}_3 \cdot 6\text{H}_2\text{O}$. That all minerals of the uranotile group, viz. uranotile, sklodowskite, and cuprosklodowskite have six molecules of water, has been confirmed by Billiet through roentgenometric studies (2). Schoep originally attributed to these minerals seven molecules of water. With reference to β -uranotile, it does not seem probable that a different degree of hydration could be the cause of its properties differing so considerably from normal uranotile.

ANALYSIS OF THE β -URANOTILE FROM JÁCHYMOV

	I	II Theoret. values
	%	%
SiO ₂	13.11	14.02
UO ₃	66.29	66.81
CaO	7.32	6.55
H ₂ O	12.87	12.62
CO ₂	not determined, but present in small quantity	—
	99.59	100.00

Under the microscope β -uranotile shows a prismatic or needle-shaped habit; at times its crystals are rather tabular with (010) predominating. The dimensions vary, usually being about 0.1×0.03 mm. In the vertical

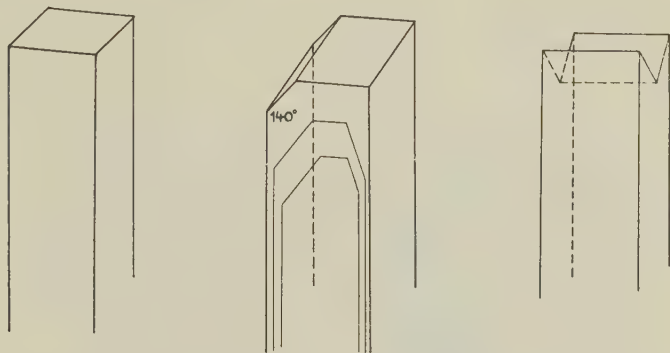


FIG. 1. Common types of β -uranotile from Jáchymov. The first type (left) is the rarest at Jáchymov, whereas it is the most common type on the β -uranotile from Wölsendorf. On the second type (center) a face of a positive orthodome and zonal character are seen. The third type (right) is a contact twin after (100).

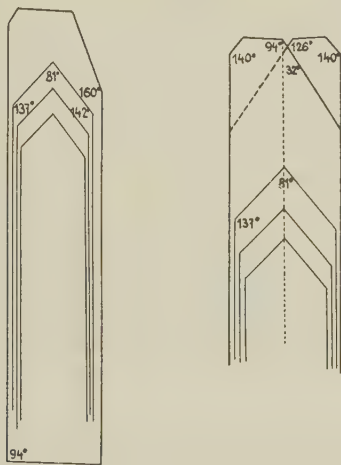


FIG. 2. Zonal character and twinning of β -uranotile from Jáchymov. The angular values are only approximate.

zone the two pinacoids (010) and (100) are developed; the prisms are terminated by faces of the orthodiagonal zone. One of these, taken as (001), is almost perpendicular to (100), having the angle ρ about 4° , making $\beta = 94^\circ$. Besides this face, we find on all crystals positive and

negative orthodomes with ρ values of 50° for $(\bar{h}0k)$ and 58° for $(h0k)$; the former corresponds to the orthodome found by goniometric measurements with the angle $\rho = 48^\circ 36'$. Another orthodome has an angle ρ of about 70° (Figs. 1, 2).

The β -uranotile from Jáchymov differs from that of other localities by the zonal development of its crystals, which is best observed on the clinopinacoid. The zones are sharply outlined by the orthopinacoid (100) and orthodomes, which are generally identical with those observed as

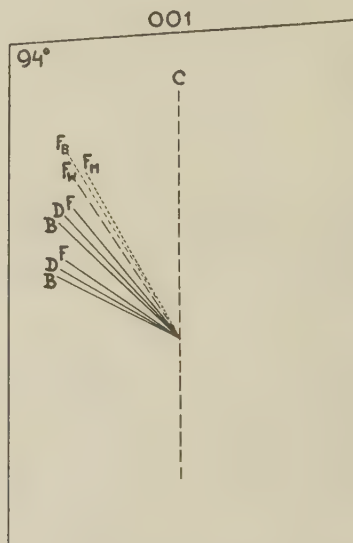


FIG. 3. Extinction angles $c:\gamma$ on the clinopinacoid of β -uranotile. The maximum and minimum extinctions of β -uranotile from Jáchymov (spectrum lines B , D , and F) are indicated by full lines, the extinction for green light (line F) of β -uranotile from Bedford (F_B), Mitchell Co. (F_M) and Wölsendorf (F_W) by dotted lines. To avoid confusion, the extinctions for red (B) and yellow (D) light are not given for β -uranotiles from the latter localities.

faces with $\rho = 50^\circ$ and 58° . The basal pinacoid (001) as a rule is absent in the outline of the zones (Fig. 2). In each zone the optical constants change continually from the center to the outside boundary. At the opposite side the sequence is repeated in the same or in a slightly different manner.

As stated above, almost all crystals of β -uranotile from Jáchymov are twinned on (100) and frequently they grow together in the same plane (Fig. 4). In more complicated cases they resemble the Carlsbad twins of feldspars, one individual being partially covered by the other (Fig. 2).

The optical symmetry of β -uranotile is monoclinic, agreeing perfectly with the results of the goniometric investigations. The pleochroism is very distinct in sections other than those parallel to (010). In the orthodiagonal direction the crystals are entirely colorless or of a faintly yellowish color. In the directions of β and γ , which lie in the plane of (010), the color is lemon-yellow without a perceptible difference of absorption between the two directions.

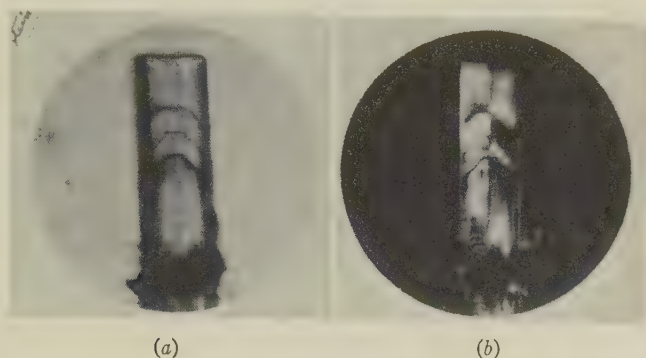


FIG. 4. (a) Photomicrograph of a twinned and zoned crystal of β -uranotile from Jáchymov in ordinary light. The re-entrant angle at the contact of the basal pinacoids is visible. In the outlines of the zones, the faces of orthopinacoid and orthodomes are very prominent, but the (001)-faces in this case also distinct. $\times 100$.

(b) The same crystal between crossed nicols. The composition plane and the imperfect extinction in different zones is quite distinct. $\times 100$.

On (100) the extinction is parallel to the vertical and orthodiagonal axes and shows no dispersion. The longitudinal direction in this case is always positive. On the contrary, if the prismatic crystals lie on the clinopinacoid, which is the most frequent case with fragments, (010) being the plane of perfect cleavage and often the plane of tabular development, they show an oblique extinction and a very strong dispersion, so that in white light in no position is the extinction complete for all colors (Fig. 3).

In red light (approximately the B -line = 687μ) the extinction has been determined to be:

(a) $\gamma:c = 46^\circ - 50^\circ$ in the zones of higher refraction

(b) $\gamma:c = 54^\circ - 60^\circ$ in the zones of lower refraction.

For sodium light (line $D = 589\mu$)

(a) $44^\circ - 48^\circ$

(b) $52^\circ - 57^\circ$

For green light, near the line F (486μ)

(a) $39^\circ - 43^\circ$

(b) $50^\circ - 55^\circ$

The extinction direction γ lies in the obtuse axial angle β (Fig. 3). With the higher refraction and smaller angle $c:\gamma$, the birefringence increases (see table of refractive indices and birefringence).

The conclusion to be drawn from the extinction angles in the different zones of growth is that the β -uranotile of Jáchymov is an isomorphous mixture of at least two components, the crystallization of which took place rhythmically and rather regularly. At the beginning of each crystallization phase the substance of lower refraction was formed, characterized also by a greater extinction angle $c:\gamma$, and subsequently the substance of higher refraction and a smaller extinction angle increased in amount. Therefore we always find the substance with lower refraction in the zone near the center of the crystal, the other substance with a higher refraction in the outer portions. Naturally these features are not absolutely equal in all crystals and in all zones, but nevertheless the crystallization sequence from the substance of a lower refractive index and greater angle, $c:\gamma$, to the substance of higher refraction and smaller angle, is constant.

The refractive indices have been determined by the method described above for red (*B*), yellow (*D*), and green (*F*) light and for the different parts of the growth zones. Unfortunately the zonal development and the forms of the zones, in most cases, have not allowed exact measurements of all refractive indices in each part of a zone.

In the accompanying table are given the mean values of a whole series of determinations of refractive indices.

The cause of the zonal development of the β -uranotile from Jáchymov and the anomalies in the optical properties in different parts of the zones remains uncertain. The variable water content alone can not be held responsible for so great differences in physical properties. It seems more probable that a relatively small admixture of another substance (a lead compound?) or a different degree of oxidation of the uranium may be the reason. The presence of lead has not been proved in the samples from Jáchymov, but a minute quantity of lead is not excluded and on the compact specimens of uranotile or of the so called "uranophane" from Mitchell Co., as will be pointed out below, the lead content has been established. A final solution of this question would be possible only if a sufficient quantity of pure material of both extreme portions could be obtained for an analysis.

β -URANOTILE FROM BEDFORD, NEW YORK

Miss E. J. Armstrong described in this Journal (1) a mineral, which she determined according to Larsen's tables (5, 6) as schroeckingerite. It is evident that this mineral is β -uranotile, as shown from the data given: Extinction $30^\circ \pm$, strong dispersion $r > v$, negative, $2V = 40^\circ - 45^\circ \pm$, $\alpha = 1.658$, $\beta = 1.682$, $\gamma = 1.685$; ± 0.003 . Pleochroism $X (\alpha) =$ colorless, $Y (\beta) =$ very pale greenish-yellow, $Z (\gamma) =$ pale greenish-yellow.

In reply to a letter from one of the writers (R. Nováček) Miss Armstrong says: "... observed the CO_2 test through a $14\times$ lens ... and it seemed to effervesce slightly. This was probably due to admixed calcite." Another specimen, examined later, "... seemed to dissolve or disappear in the acid, but without noticeable effervescence." Consequently the mineral from Bedford also corresponds chemically to a silicate rather than to a carbonate though SiO_2 has not been determined because of the small quantity.

Miss Armstrong has kindly sent us a minute amount of the "schroeckingerite" from Bedford, and a sample of the pegmatitic rock with minute needles of the mineral in question. We have been able to verify its identity as β -uranotile.

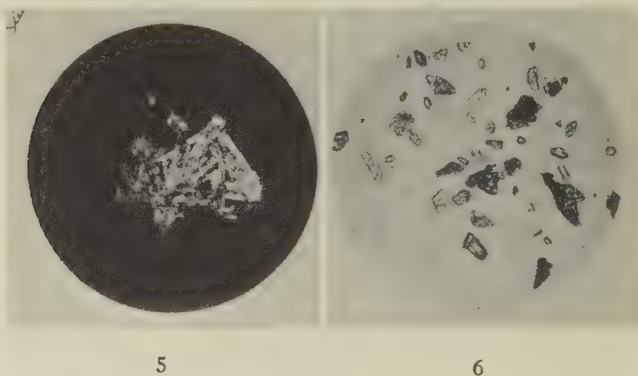


FIG. 5. Photomicrograph of the β -uranotile from Bedford (crossed nicols): a radiated aggregate of β -uranotile with distinct twinning of some individuals after (100). $\times 30$.

FIG. 6. Photomicrograph of the β -uranotile from Mitchell Co., N. Carolina; the admixture of quartz is visible. Ordinary light. $\times 15$.

Under the microscope the needles and prisms of β -uranotile from Bedford are grouped to form radial aggregates (Fig. 5) and the crystals show in the vertical zone the two pinacoids (100) and (010). The terminal faces (001) are observed in some cases. The twinning after (100) is very frequent, the individual crystals of the twins, like the β -uranotile from

Jáchymov, either grow together in the plane of (100) or partially overlap each other.

The extinction on (010) is:

$$c:\gamma_B = 37\frac{1}{2}^\circ - 40^\circ$$

$$c:\gamma_D = 35^\circ - 37\frac{1}{2}^\circ$$

$$c:\gamma_F = 29^\circ - 33^\circ$$

The extinction on (100) is parallel.

There is no distinct zonal structure similar to that shown on the crystals from Jáchymov. The apparent zoning of some prisms is caused by the mutual overlapping of the individuals of the twin-crystals.

β -URANOTILE FROM MITCHELL CO., N. CAROLINA

In the British Museum of Natural History in London there is a sample of pegmatite from Mitchell Co. (No. 191, B. M. 1929) with a yellow, compact, and crystalline mineral, designated as schroeckingerite (locality: Near Spruce Pine, Mitchell Co., N. Carolina). From a detailed study the crystalline parts of the yellow mineral also proved to be β -uranotile; the determination as schroeckingerite seems to have been made according to the data of Professor Larsen.

The pegmatite mother rock of β -uranotile consists of quartz, cyrtolite, muscovite and feldspar with massive "uranophane." The crystals are densely aggregated in small cavities and penetrate the quartz so intimately that they cannot be completely separated. Even minute fragments, which appear macroscopically quite homogeneous, show when crushed, a considerable admixture with quartz (see the photomicrograph 6). Therefore it has not been possible to determine the exact value of the density, nor to carry out a quantitative chemical analysis on perfectly pure material. A sample of 4.5 mg. of a mixture of β -uranotile and quartz was taken and the results are given below in column I. Even a separation using acetylene tetrabromide did not succeed in isolating a sufficient quantity of pure material. This would have necessitated crushing to a very fine powder in which the losses would have been too great. However, 1.7 mg. of β -uranotile were obtained for another microanalysis, the results of which are given in column II.

	I		II	
	%	Ratios	%	Ratios
SiO ₂	31.9	2+3.7 (quartz)	29.3	2+3 (quartz)
UO ₃	53.5	2	56.4	2
CaO	4.8	0.9	5.0	0.9
H ₂ O	9.9	5.9	10.2	5.8
	100.1		100.9	

Both analyses clearly show that the ratios of $\text{UO}_3:\text{CaO}:\text{H}_2\text{O}$ are the same as in other analyses of uranotile and β -uranotile, *i.e.*, 2:1:6. The higher silica ratio corresponds to the admixture of quartz, about 20%, according to the microscopical examination on the analyzed material.

The compact uranotile from the Flat Rock mine, Mitchell Co., was analyzed previously by F. A. Genth (4) and the results of both of his analyses (one incomplete) agree well with the theoretical values for uranotile.

ANALYSES OF MASSIVE URANOTILE (GENTH)

	I	II	Theoret. values
	%	%	%
SiO_2	13.55	13.88	14.02
UO_3	66.67	66.59	66.81
$\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$	traces	traces	—
CaO	6.23	7.11	6.55
H_2O	not determ.	12.02	12.62
PbO	0.74	0.45	—
SrO, BaO	0.42	0.48	—
P_2O_5	not determ.	0.29	—
		100.82	100.00

From several partial analyses of a compact “uranophane” from Mitchell Co. we obtained:

SiO_2	14.5%,	14.8%	and	15.0%
UO_3	61.5%,	62.0%		
H_2O	14.2%,	14.0%		

CaO was not determined; the sesquioxides, principally Al_2O_3 , are present to the extent of 2.5% and $\text{PbO} = 2.1\%$.

The “uranophane” from Mitchell Co. evidently contains a considerable quantity of impurities; the most interesting of them is lead (admixed gummite?), which might be able to cause essential differences in the optical properties of β -uranotile.

As a result of the comparison, we find that refractive indices of β -uranotile from Spruce Pine correspond to the zones of higher refraction in the crystals of the Jáchymov mineral, and the angle of extinction is smaller than in the zones of highest refraction (Fig. 3). No zonal change in optical properties, nor twinning, have been observed on the mineral from Spruce Pine.

In other features a complete identity with β -uranotile has been observed. The crystals show both vertical pinacoids and positive and negative orthodomes (the angles of the latter being in most cases $\rho = 44^\circ$ for the positive, and 48° for the negative orthodome). The base is often absent.

The density could not be determined accurately because of admixture with quartz; the result of a determination made by the suspension method is about 3.8.

The color of the crystals is a more intense yellow than in the β -uranotile from Jáchymov, with identical pleochroism (α =colorless, β and γ =yellow).

Extinction angles:

$$c:\gamma_B = 36^\circ$$

$$c:\gamma_D = 32\frac{1}{2}^\circ$$

$$c:\gamma_F = 29\frac{1}{2}^\circ$$

The anomalies observed on different crystals are unimportant. The mean values of the refractive indices for different wave-lengths are:

α			β			γ		
<i>B</i>	<i>D</i>	<i>F</i>	<i>B</i>	<i>D</i>	<i>F</i>	<i>B</i>	<i>D</i>	<i>F</i>
1.661	1.663	1.668	1.684	1.688	1.693	1.691	1.697	1.707

The angle of the optic axes, determined graphically from the projection of the measurements on the universal stage, is

$$2V_B = 63\frac{1}{2}^\circ$$

$$2V_D = 62^\circ$$

$$2V_F = 60^\circ$$

β -URANOTILE FROM WÖLSENDORF

In 1931 Professor A. Schoep and Dr. A. Scholz described (12) several uranium minerals, new for this locality in Bavaria, known as the original locality for uranotile. Up to that time these minerals had been described almost without exception only from the Belgian Congo. On one specimen the writers observed several yellow needle-like translucent crystals whose identity with any known mineral had not been established. The brief description of the optical properties* points, here also, to β -uranotile.

* "Yellow translucent crystals with a perfect cleavage parallel to a plane on which the acute bisectrix is observed. $2V$ relatively small, optical character negative. $N = 1.69$, $n = 1.68$. Between crossed nicols, in white light, the crystals show anomalous blue interference colors and the extinction is imperfect. The direction N forms an angle of 20° – 30° to the longitudinal cleavage fissures and to the twin borders."

Our attention has been drawn to this mineral by Dr. Scholz, who kindly sent us a small quantity for investigation. In a letter from Dr. Scholz he has pointed out a great similarity in the properties of the Wölsendorf mineral and the "schroeckingerite" of Dr. Larsen, and has shown that it is a silicate.

The qualitative tests have shown the presence of SiO_2 , UO_3 , CaO and H_2O . In dissolving in acids sometimes a few gas bubbles escape, but it is not certain if they are CO_2 . Gas inclusions are present also in the crystals, so that the crystals are cloudy. This is a distinct difference between the β -uranotile from Wölsendorf and the normal uranotile from this locality and the American and Jáchymov β -uranotiles.

The quantitative microanalysis (carried out on 2 mg. of material) has given the following data:

Theoretical values:		
	%	%
SiO_2	12.9	14.0
UO_3	66.9	66.8
CaO	7.1	6.6
H_2O	12.6	12.6
	99.5	100.0

The result of the analysis agrees closely with the theoretical values for β -uranotile. Only the per cent of SiO_2 is a little lower; for this difference probably an imperfect separation of silica is responsible as the evaporation with nitric acid was made only once.

The β -uranotile from Wölsendorf is not suitable for goniometric investigation. Besides both pinacoids, other faces also probably occur in the vertical zone. The orthodomes are mostly subordinate and often absent while the base is imperfectly developed. The density was determined in Clerici's solution to be 3.85.

Microscopically, besides the small cavities which cause the translucency of the crystals, the same features may be observed on the β -uranotile from Wölsendorf as on those from Jáchymov and Bedford. The individuals are relatively long (up to 2 mm.), often twinned (Fig. 7), show the same pleochroism (α =colorless, β and γ =yellow) and a strong dispersion of extinction. On the universal stage we have determined:

$$c:\gamma_B = 38\frac{1}{2}^\circ$$

$$c:\gamma_D = 36^\circ$$

$$c:\gamma_F = 33^\circ$$

The refractive indices for different wave-lengths are:

α			β			γ		
<i>B</i>	<i>D</i>	<i>F</i>	<i>B</i>	<i>D</i>	<i>F</i>	<i>B</i>	<i>D</i>	<i>F</i>
1.665	1.668	1.672	1.681	1.686	1.701	1.690	1.695	1.709(?)

$$\Delta_B = 0.025$$

$$\Delta_D = 0.027$$

$$\Delta_F = 0.037(?)$$

According to a personal communication, Dr. Scholz has observed an interesting phenomenon which would support the view that β -uranotile

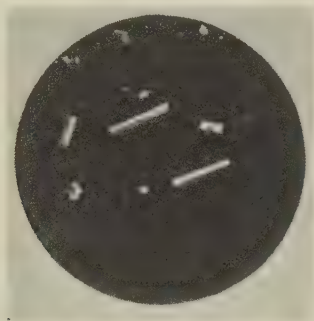


FIG. 7. Photomicrograph of twinned crystals of β -uranotile from Wölsendorf, Bavaria. Crossed nicols. $\times 15$.

is a rather labile modification of the substance $\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$. Several crystals, evidently β -uranotile, when crushed formed small pieces of acicular shape, the properties of which (extinction and refractive indices) correspond to normal uranotile. On a specimen sent us by Dr. Scholz we have noted the same change.

Concerning β -uranotile there still remains much to solve. Perhaps in the course of time we shall succeed in finding suitable material, which will enable us to finish the investigation of these unexplainable features.

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NOTES AND NEWS

CORUNDUM IN A DIKE AT GLEN RIDDLE, PENNSYLVANIA

W. HAROLD TOMLINSON, *Swarthmore, Pennsylvania.*

GENESIS OF CORUNDUM

The genesis of corundum is such an interesting problem that it has intrigued mineralogists of all times. A lengthy literature concerning the mineral has accumulated but the conclusions reached as to its genesis have varied widely. With such diverse opinions expressed it is necessary to proceed slowly in accepting a viewpoint, as the mineral may be formed perhaps in several different ways.

Morocowicz showed that corundum can be crystallized from magmas containing an excess of alumina, according to a definite law, but the laboratory experiments are not similar to the conditions under which corundum is formed in nature. It has been shown that corundum may be formed as a secondary mineral in corrosion rims, but this type of genesis is applicable to only a very small number of unimportant deposits.

In dealing with the Canadian and Indian occurrences, the geologists state that all these deposits of workable size are primary crystallizations from high-alumina magmas, in accordance with Morocowicz's law, but in describing these deposits they state that all workable concentrations occur in pegmatites. Their description would seem to contradict their statement as to origin. Since corundum is known to be the first mineral to separate from high-alumina magmas on cooling, it could hardly be concentrated in the pegmatites derived from these magmas.

The writer has recently been impressed by the evidence that corundum is not a primary pyrogenic mineral, but that it has developed through volatile reactions at a high temperature, *i.e.*, at the highest temperature at which volatiles can be expelled from the magma. The pyrogenic mineral involved in these reactions, the writer believes to be anorthite, the calcic end member of the plagioclase series. This feldspar containing 36.7% alumina is generally abundant in corundum-bearing formations. Where the corundum develops in these formations, the anorthite (or plagioclase containing the anorthite molecule) usually shows the effects of an attack by volatile constituents.

Two reactions by which corundum is formed from anorthite have been described in the literature: one, the so-called "corrosion rim" reaction between anorthite and hypersthene by which actinolite and corundum are developed; the other, a reaction between anorthite and olivine with the formation of hornblende and corundum. Since both reactions start with pyrogenic (water-free) minerals and develop a mineral (actinolite

or hornblende) containing hydroxyl, both reactions must result from an attack by volatiles at sub-magma temperatures.

A third reaction involving anorthite, by which the writer believes corundum may be developed, is the reaction by which antiperthites are formed. This process appears to have operated extensively where corundum deposits occur in high plagioclase or alkaline rocks. In this reaction a feldspar of the potash-barium type, relatively low in alumina and high in silica, replaces a feldspar of the lime-soda series, relatively high in alumina and low in silica. The reaction requires potash in alkaline solution, and possibly also barium, and is therefore confined to alkaline rocks or to rocks invaded by alkaline solutions. As a result of the replacement, one half of the alumina in the anorthite will be set free. The writer believes that this alumina is available for the development of corundum under certain physical conditions, and with proper chemical environment. The solutions remaining after this reaction are still alkaline but carry soda and lime, instead of potash and barium. These alkaline solutions could transport this free alumina short distances before precipitation, hence the large corundum crystals in the alkaline pegmatites.

As a possible illustration of this principle we offer a description of the corundum occurring in a dike at Glen Riddle, Pa., which the writer has recently studied jointly with Mr. A. E. Meier.

DESCRIPTION OF CORUNDUM BEARING DIKE AT GLEN RIDDLE, PA.

The dike at Glen Riddle carrying corundum is a narrow plagioclase dike of gabbroid composition cutting serpentized pyroxenite. Along the border zones of the dike the plagioclase carries from 30% to 50% anorthite. Toward the centre of the dike the plagioclase changes to a sodic oligoclase. This dike shows numerous crushed zones paralleling the walls. These have been invaded by volatiles which we believe had a granitic origin. We have found feldspars similar to the feldspars of these zones in another dike nearby which is unmistakably granitic. All formations in this district have been extensively invaded by volatiles of granitic origin. There is no other igneous body in the district from which these volatiles could have originated.

These volatiles have reacted with the plagioclases of the dike to form potash-barium feldspars, hyalophane, and antiperthites consisting of a plagioclase host invaded by a potash-barium feldspar. A fuller description of the dike and its field relations will be given in a paper by Mr. Meier.

The corundum is found in the crushed zones with hyalophane, and only in these zones where they cut the calcic feldspar along the border of the dike. Where the crushed zones cut the sodic plagioclase we find

hyalophane, but no corundum associated with it. We do not know how this feldspar replacement is accomplished, but consider it a substitution of potash and barium for the soda and lime of the original plagioclase, under alkaline conditions. What role the barium may play in the reaction chemically, we do not know. We note that Pratt and Lewis in describing a similar dike at Buck Creek, N. C., mention barium minerals with the corundum. The percentage of barium in antiperthites at corundum localities, as far as we know, has not been investigated.

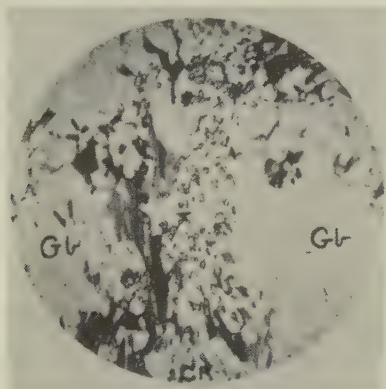


FIG. 1. Crushed zone containing corundum. "Cr," fine-grained hyalophane and corundum; "Gb," coarse-grained gabbroid minerals, chiefly plagioclases of dike. $\times 8.1$ nicol.

The corundum at Glen Riddle is interpreted as representing the excess alumina of the labradorite over the alumina content of hyalophane. The most anorthitic lime-soda feldspar found in the dike is a 50% labradorite containing 28.2% alumina, the most celsic potash-lime feldspar is a 16% hyalophane with 19.5 alumina. The difference in alumina, 7.7%, is approximately the percentage of corundum associated with the hyalophane in the crushed zones. It is not possible to give exact percentages as there is a continuous variation in composition both in the plagioclase and in the hyalophane. There is also a variation in the percentage of corundum at different points along the crushed zones, but this we believe can be explained by transportation of the alumina set free in the alkaline solutions before precipitation. We can say that the average percentage of corundum in these crushed zones is of the same order as the percentage of alumina that would be freed if the reaction took place as indicated, namely, approximately 7.7%. The formation of corundum at Glen Riddle, as here interpreted, is shown in the accompanying photomicrographs.



FIG. 2. Development of corundum from plagioclase. Section taken at border of crushed zone. "L," labradorite of dike with about 28.2% alumina; "H," hyalophane with approx. 19.5% alumina. Arrow points to antiperthite showing attack on plagioclase grain with embayment and penetration by hyalophane. $\times 75$. 1 nicol.

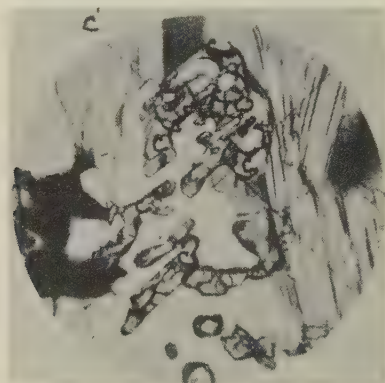


FIG. 3. Crystal grain of corundum assumed to have been formed from alumina freed by attack on plagioclase. All corundum grains, "C," behave as one crystallographic unit. White inclusions, hyalophane with various orientations. Cross-hair C' parallel to vertical axis of corundum. $\times 130$. 1 nicol.

SUMMARY OF DATA

This view is supported by the following:

1. The general association of corundum with alkaline rocks which could furnish the volatiles necessary for the liberation and transportation of hydrated alumina.

2. Types of formations in which corundum is concentrated—pegmatites and veins in high-alumina rocks, banded rocks, narrow plagioclase dikes, contacts, sediments near contacts. In all cases these formations are cut by channels through which volatiles may pass.

3. Abundant presence of anorthite molecule or a plagioclase at all corundum localities and evidence of volatile activity at these localities. The alumina content of anorthite is so high that any reaction involving the mineral would be likely to free some alumina. Anorthite is readily attacked by volatiles.

4. Presence of antiperthites in corundum-bearing plagioclase rocks. Corundum usually increases as these increase and disappears when these are absent.

5. Presence of zones or veins of lime or lime-soda minerals containing hydroxyl at many corundum localities.

6. The large size of corundum crystals in pegmatitic dikes.

7. Movement of alumina in nature suggests dissemination in magma and concentration by volatile activity.

8. Many natural crystals of corundum contain water inclusions.

9. Analyses of natural corundum show a variable ignition loss.

10. Parallel development of corundum and hematite in emery.

11. Frequent occurrence of corundum crystals partially replaced by muscovite, or similar secondary minerals. Corundum that has crystallized from a melt as a primary crystallization product is chemically inert and resists all attack by either acids or bases. It seems improbable that corundum so formed could be altered by any natural process. Alumina set free through volatile attack is chemically active and will combine with either acids or bases. Corundum crystals thus formed might retain some chemically active alumina (hydrated alumina) to respond to natural agencies yielding crystals partially replaced by muscovite or other similar minerals. No one has been able to prove as yet that corundum crystals can be developed from hydrated alumina, but laboratory experiments have shown that this alumina changes to corundum at 800°C., and the opinion has been expressed that this change might occur in nature at a lower temperature if given a longer period of time than is possible in laboratory experiments.

CONCLUSION

It has been the object of this paper to call attention to the possible formation of corundum deposits by high-temperature volatile reactions on calcic plagioclases.

LARGE SPHENE CRYSTALS FROM SAN JACINTO
MOUNTAINS, CALIFORNIA

ROBERT W. WEBB,

University of California at Los Angeles.

INTRODUCTION

Large sphene crystals disseminated in plutonic rocks are not commonly found. Recently an area was discovered in the San Jacinto Mountains, Riverside County, California, in which numerous large crystals of sphene occur in grandiorite in sizes up to $1'' \times \frac{1}{2}'' \times \frac{1}{2}''$.

LOCATION

A few years ago a fine road generally known as the "Palms to Pines Highway," was completed across the San Jacinto Mountains, connecting Hemet, California, with Indio, in the Coachella Valley. This road opened up much country otherwise inaccessible. The sphene was found in exposures along this highway, approximately four miles toward Indio from a small roadside camp known as Ribbonwood. The locality lies on the northwestern side of Deep Canyon, in T. 6S., R. 5E., Sec. 36, Indio quadrangle.

DESCRIPTION OF THE SPHENE

The crystals are perfectly formed euhedrons, occurring separately and in groups, with individual crystals more common. Literally thousands of crystals of good size are obtainable without difficulty. The forms, as seen in the accompanying photograph (Fig. 1) are: $a(100)$, $c(001)$, $x(102)$, and $n(111)$. Examination of many perfect crystals and many fragments showed only these forms.

The crystals generally show small inclusions of feldspar and quartz. Microscopic examination of the individuals shows crystals of sphene completely enclosing andesine, which is commonly subhedral in relation to the sphene. They also enclose quartz, which occurs in anhedral. Some of the sphene shows alteration to leucoxene.

The sphene occurs in an area within the large granitic batholith of the San Jacinto Mountains. The map of Fraser¹ shows batholithic rocks to the west, apparently the equivalent of those in which the sphene is found, which are classed as granites. The rock in the vicinity of the sphene locality is a granodiorite, varying to a microcline-quartz diorite. In

¹ Fraser, Donald M., Geology of San Jacinto quadrangle south of Gorgonio Pass, California: *Calif. Dept. Nat. Res., Div. Mines, Mining in Calif., State Mineralogist's Rept.*, vol. 27, 494-540 (1931).

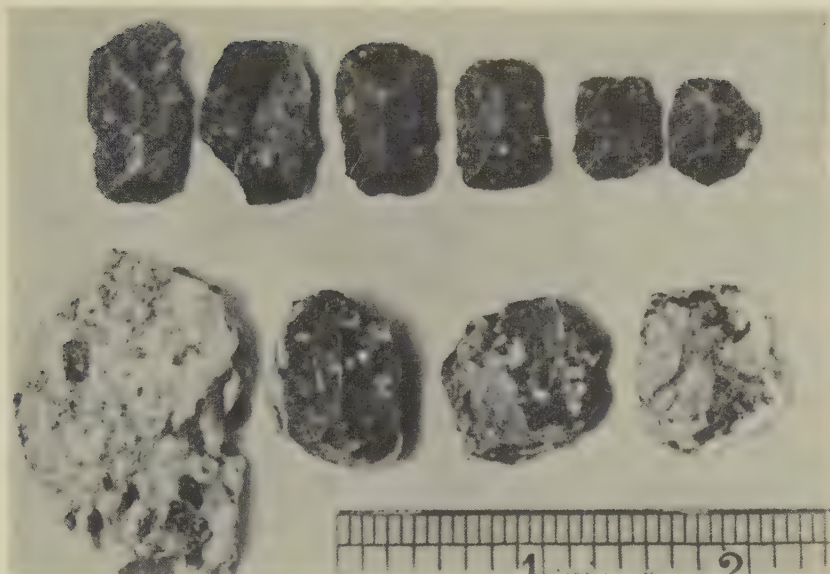


FIG. 1. Large sphene crystals from San Jacinto Mountains, California, showing occurrence of euhedrons, aggregates, and inclusions.

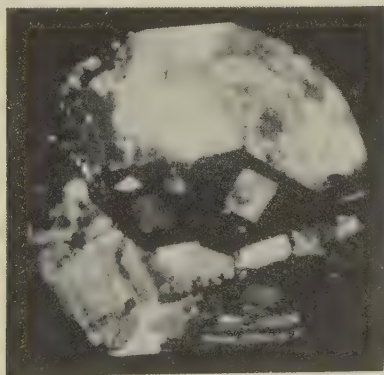


FIG. 2. Photomicrograph ($\times 13$) showing a large euhedron of sphene including subhedral andesine and quartz, from the microcline-quartz diorite of the San Jacinto Mountains.

the typical rock one to three per cent of sphene is common. Within an irregular area of several hundred square yards, high concentrations of sphene were noted with percentages running as high as five to ten per cent. In this area the large crystals here described were found. Deep

weathering of the feldspars of the country rock has caused excessive disintegration with the subsequent formation of a coarse soil in which the sphene crystals are disseminated, having resisted the attack of the desert agents. One is thus able to secure thousands of these crystals by either hand-picking, or sieving the top-soil. Where small swales are encountered, the top soil has been removed and one finds the sphene crystals particularly abundant, concentrated by the removal of the lighter weathered materials.

ORIGIN OF THE SPHENE

The occurrence of many grains of subhedral andesine and quartz included in the sphene crystals indicates a secondary introduction of titanium solutions into the granodiorite. The presence of accessory sphene in the rock in general and the textural relations of the sphene to minerals normally formed later, makes it improbable that the solutions carrying the titanium were original to the magma, but suggests that they were introduced from a secondary source after the partial or complete consolidation of the granodiorite. Field studies failed to indicate the source of the materials from which the sphene might have been derived. Further indication of alteration of the rocks in the sphene area is the presence in some places in the country rock of myrmekitic intergrowths.

CORRECTIONS AND ADDITIONS

W. T. SCHALLER, *U. S. Geological Survey.*

In the article on inesite in the January issue (vol. 24, p. 26), Piedmont (Lake Crescent), Oregon, should read Piedmont (Lake Crescent), Washington.

An additional locality should have been listed for thaumasite on pp. 878-880 of the December, 1938 (vol. 23, no. 12) issue. Professor B. S. Butler of the University of Arizona has called my attention to the description of thaumasite at the Lucky Cuss mine near Tombstone, Arizona.¹ The thaumasite "fills small fissures and replaces altered limestone. . . . The thaumasite is believed to have resulted from the action of hypogene sulphated waters upon siliceous limestone or upon calcium silicates previously formed by contact metamorphism." The localities in New Jersey still remain the only ones in which it can be shown that the thaumasite was derived from a sulphate mineral and such an origin, therefore, seems to be unique instead of a common one.

¹ Butler, B. S., Wilson, E. D. and Rasor, C. A., Geology and ore deposits of the Tombstone district, Arizona: *Bull.* 143, *Geological Series 10, Arizona Bureau of Mines*, pp. 62-63 (1938).

The total number of localities of thaumasite now becomes 14, distributed in three countries, the United States, Sweden, and Hungary;² with seven States in the United States.

² See note, *Am. Mineral.*, **23**, 880 (1938).

BOOK REVIEW

DESCRIPTIVE LIST OF THE NEW MINERALS 1892-1938. George Letchworth English. 258+VII pages. McGraw-Hill Book Co., Inc. New York, 1939. Price \$3.00.

The author has brought together a descriptive list of over 2200 new English names that have appeared in the literature during the past forty-six years. The names with brief descriptions are arranged alphabetically and have been compiled from accounts that have appeared in the three Appendices of Dana's *System of Mineralogy*, Dana's *Textbook*, fourth edition, *The American Mineralogist*, *The Mineralogical Magazine*, *Mineral Abstracts* and *Chemical Abstracts*. A reference to the original description, and in many instances a number of references is given for each name. An Appendix summarizes the report of the Committee on Nomenclature which was adopted recently by the Mineralogical Society of America.

The author has performed a worthy service for mineralogical science in making available in a concise form information and data covering a long period of years and widely scattered throughout the literature.

W.F.H.

PROCEEDINGS OF SOCIETIES

MINERALOGICAL SOCIETY OF GREAT BRITAIN AND IRELAND

March, 9th, 1939

Dr. L. J. Spencer, President, in the chair.

EXHIBITS:

On W. Thomson's and other mineral collections of the 18th century. By Dr. R. T. Gunther.

Minerals from Mina da Panasqueira, Fundao, Beira Baixa, Portugal. By Mr. Arthur Russell and Dr. W. R. Jones.

A model showing the morphological relationships in glide-twinning in calcite. By Dr. F. Coles Phillips.

The examination of pebbles under the low power binocular microscope. By Dr. A. K. Wells.

Some Mendip minerals. By Mr. A. W. Kingsbury.

The following papers were read:

(1). *The Wherry Mine, Penzance, its history and its mineral productions*. By Mr. ARTHUR RUSSELL.

(2). *On the presentation of chemical analyses of minerals*. By Dr. MAX H. HEY.

A discussion of the calculation of absolute atomic cell contents, with especial attention to probable errors; also of the calculation of atomic ratios to assumed bases (often called atomic cell contents) and of calculated densities.

(3). *A note on kaolinite in some "eenie" coals*. By Dr. G. F. CLARINGBULL.

X-ray and optical data show that thin brownish or white disks from the "een" of certain coals are roughly oriented aggregates of kaolinite.

(4). *Biographical notices of mineralogists recently deceased. (Seventh series).* By Dr. L. J. SPENCER.

Twenty-nine obituaries with eight portraits are presented for the period 1936-39. Ages range from 32 to 93 with an average of 72.2 years, showing a further slight increase.

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences, Philadelphia, Pa.

January, 5, 1939

A meeting of the Philadelphia Mineralogical Society was held on Jan. 5, 1939, with 55 members and 29 visitors present. President Harry W. Trudell presided.

Mr. Adolph E. Meier spoke on the presence of barium in the harmotome of the diorite dike cutting serpentinite at Glen Riddle, Pa. While the outer portion of the dike is quite basic, consisting of 75% of sodic labradorite and 10% biotite, the central portion contains 90% of an acid plagioclase and 10% of biotite. Solutions continued to flow through this portion after consolidation. The original feldspar was thought to be andesine. Hyalophane, the barium-potash feldspar, was formed at a high temperature as antiperthite. At a lower temperature, oligoclase replaced the antiperthite, releasing the barium to form harmotome crystals which are found in the joint fissures.

Mr. W. Harold Tomlinson discussed the origin of free alumina in rocks, using the corundum in the Glen Riddle dike as an example. He pointed out that along crush-zones where solutions of high temperature had easy access to andesine, hyalophane replaced it releasing alumina, which crystallized nearby as corundum. The speaker believes that many deposits of corundum can be explained by the release of free alumina when basic feldspars are transformed to a potash feldspar.

Mr. William Parrish showed, with the aid of atomic structure models, the relationship between internal structure and physical properties. He discussed Bowen's reaction series in the light of the linkage of silica tetrahedra. A satisfactory explanation of the crystallization of high temperature forms from impure solutions at lower temperatures is possible by a comparison of the structures of the high and low temperature modifications. The form stable at the higher temperature has an open structure, while in that of lower temperature the atoms are more closely packed. However, should the mineral crystallize from a solution which contains foreign atoms which might become wedged in the spaces of the open structure, preventing its collapse, a high temperature form would result instead of the expected stable form.

Dr. Gillson gave a summary of the 50th anniversary meeting of the Geological Society of America.

Mr. Gordon gave a brief report of his trip to Chile and Peru.

LOUIS MOYD, *Secretary*

Academy of Natural Sciences of Philadelphia

February 2, 1939

A meeting of the Philadelphia Mineralogical Society was called to order by President Harry W. Trudell, with 53 members and 28 visitors in attendance.

Dr. Edward P. Henderson, of the U. S. National Museum, addressed the society on *The Mineralogy of Meteorites*. He stated that about 1200 meteorites of sufficient size to sample and study were known and that all could be classified as either iron meteorites, stony and iron meteorites, or stony meteorites. Iron meteorites are of three types, hexahedrites, octahedrites, and ataxites. Hexahedrites show plates arranged parallel to cubic

faces, octahedrites contain plates with trigonal arrangement, while ataxites are granular. Most of the larger meteorites are ataxites.

Dr. Henderson compared the compositions of the nickel-iron alloys of meteorites with the results of laboratory studies, finding many significant similarities. He found that when the nickel present reached 5.5%, kamacite formed, but when nickel was in excess of this amount, taenite plates separated out together with kamacite. In the stony iron types, olivine is the most common mineral and although it contains only 10% of iron, there is no reaction between it and the iron of the meteorite.

The stony meteorites are of two types, one of intergrown crystals, the other consisting of rounded particles up to 1 cm. in diameter called chondrules. The chondrules vary in composition and structure, some consist of enstatite crystals and glass, others of olivine and glass, and still others show crystal fragments in glass.

Often meteorites are found composed of both octahedrite and hexahedrite types, while others show a variety of chondrules. Dr. Henderson believes these heterogeneous types result from the recementation or refusion of earlier materials. Many meteorites show slickensides and evidence of faulting, probably due to the high but uneven pressures developed as the bodies fall. The address was illustrated with specimens and lantern slides.

LOUIS MOYD, *Secretary*

Academy of Natural Sciences of Philadelphia

March 2, 1939

President Harry W. Trudell called the meeting of the Philadelphia Mineralogical Society to order, with 56 members and 37 visitors in attendance.

In a report entitled *Collecting Minerals in Chile*, Mr. Samuel G. Gordon described his trip through the Atacama desert during the latter part of 1938. The Atacama desert, he said, had been shattered by earthquakes and thus was very pervious to mineralizing solutions. Many valuable deposits are to be found within the area. The first report on the area was given over 100 years ago by Charles Darwin who described some of the gold and nitrate workings. Mr. Gordon exhibited many beautiful specimens that had been collected on the trip and illustrated his discussion with an attractive series of pictures.

Mr. Leonard Morgan exhibited an amethyst group collected at Prospect Park, N. J.

LOUIS MOYD, *Secretary*

NEW MINERAL NAMES

Bidalotite

B. RAMA RAO AND L. RAMA RAO: On "Bidalotite," a new orthorhombic pyroxene derived from cordierite. *Proc. Indian Acad. Sci.*, 5, No. 6, Sec. B, 290-296 (1937), 3 plates.

NAME: From the locality Bidaloti village, Mysore.

CHEMICAL PROPERTIES: A metasilicate of iron and magnesia with some alumina and constitutional water. Analysis: (by E. R. Tirumalachar) SiO_2 53.16, Al_2O_3 10.55, Fe_2O_3 4.30, FeO 17.10, MgO 11.95, CaO none, Na_2O trace, TiO_2 1.35, $\text{H}_2\text{O} +$ 2.00; sum 100.41. Three other analyses, showing its variable composition are given.

PHYSICAL AND OPTICAL PROPERTIES: Color lilac. Cleavage good, prismatic and at right angles. $G = 3.20-3.24$. Biaxial, negative. Parallel extinction. $2V = 57^\circ \pm 2^\circ$. Dispersion $r < v$. Optical orientation $Z = c$. $\alpha = 1.656$, $\beta = 1.667$, $\gamma = 1.672$. Biref. = .016. Pleochroism, X = pale yellow to almost colorless; Y = lilac, with slight brownish tinge, Z = lilac, pinkish violet or pale purplish pink.

OCCURRENCE: Found closely associated with cordierite, perhaps as an alteration or replacement product, in biotite-cordierite-hypersthene granulite exposed near the village Bidaloti, Koratagere Taluk, Tumkur District, Mysore.

W. F. F.

Brunckite

ROBERT HERZENBERG: Brunckit (Zinksulfidgel). *Centr. Mineral. Abt. A*, No. 12, 373-4 (1938).

NAME: In honor of Otto Brunck of Freiberg.

CHEMICAL PROPERTIES: Sulfide of zinc, Zn 65.1, Cd 2.08, S 32.1, Pb 0.12, FeO 0.38, MnO 0.04, Insol. 0.48. Sum 100.66. (H_2O and CO_2 sparingly present.)

Easily soluble in mineral acids with evolution of H_2S and separation of sulfur. Slowly soluble in acetic acid.

Before the blow pipe: In closed tube yields a silver white sublimate of cadmium; in open tube a brown sublimate of cadmium oxide; on charcoal a zinc coating with cadmium border.

PHYSICAL PROPERTIES: Color white with gray tinge. Lusterless. Pulverulent. $H. = 2\frac{1}{2}-3$. Porous, sticks to the tongue. Under the microscope, transparent, isotropic with high index of refraction.

OCCURRENCE: Found in the lead mine of Cercapuquio, west of Cerro de Pasco, Peru. In its shrinkage cracks are small crystals of smithsonite.

W.F.F.

Cuprorivaite

CARLO MINGUZZI: Cuprorivaite: Un nuovo minerale. *Periodico di Mineralogia*, 9, No. 3, 333-345 (1938).

NAME: From its supposed relationship to rivaite.

CHEMICAL PROPERTIES: Essentially a silicate of copper and calcium: $2(\text{Ca}, \text{Na})(\text{Cu}, \text{Al})(\text{Si}, \text{Al})_4(\text{O}, \text{OH})_{10} \cdot \text{H}_2\text{O}$. Analysis (sample contaminated by 13% quartz) SiO_2 64.44, SO_3 1.08, CO_2 1.18, Fe_2O_3 0.39, Al_2O_3 2.12, CuO 12.09, CaO 12.19, K_2O 1.06, Na_2O 2.52, $\text{H}_2\text{O} (+180)$ 2.59; sum 99.66.

PHYSICAL AND OPTICAL PROPERTIES: Color azure blue. $G = 2.866$. Biaxial, negative. $2V = 13^\circ$. $\alpha = 1.589$, $\beta = 1.627$. γ (calc) = 1.6275. Pleochroic, X = pale yellow, Y = azure, Z = azure.

OCCURRENCE: Found at Vesuvius intimately mixed with quartz and an unknown green mineral.

W.F.F.